NASA CR-107242
TR-1042

# VACUUM JACKETED UMBILICAL LINES TECHNOLOGY ADVANCEMENT STUDY

## VACUUM JACKETED HOSE FLEXURE

AMETEK/Straza
790 Greenfield Drive
El Cajon, California 92021

October 1969



Final Report , Task III, Sub-task 1
Contract Number NAS 10-6098

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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15. Supplementary Notes

This report is one of seven similar tasks related to vacuum jacketed components used on the service arms of the launch umbilical tower at Launch Complex 39, Kennedy Space Center, Florida.

16. Abstract

This report is a detailed study of the vacuum jacketed flex lines that are routed across the retractable service arms on the Launch/Umbilical Tower to supply cryogenic fluids to the Saturn V Vehicle. These lines experience severe heat transfer and motion conditions during operational service and abuse during handling and installation which result in premature failure of components and high frequency of maintenance and attendant costs. Conclusions based on hardware evaluation, product review, new designs and comprehensive testing are discussed and recommendations to increase the performance, durability, flexibility and reliability of these lines by developing inprovements in design, construction, and/or usage are presented.

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AMETEK/Straza
790 Greenfield Drive
El Cajon, California 92021

# FINAL REPORT

For

Vacuum Jacketed Umbilical Lines
Technology Advancement Study
Task III, Sub-task 1
Vacuum Jacketed Hose Flexure
Contract Number NAS 10-6098
October 1969

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Program Manager

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ABSTRACT

This Final Report summarizes and details the work performed to meet the requirements of the "Vacuum Jacketed Umbilical Lines Technology Advancement" at Complex 39 for Phase I (Analyses) and Phase II (Testing).

Vacuum Jacketed Flex Lines are routed across retractable service arms and supply cryogenic fluid to the Saturn V vehicle. As a consequence, these lines experience severe heat transfer and motion conditions during operational service as well as extreme atmospheric conditions which result in premature failure of components and high frequency of maintenance and attendant costs.

The purpose of this program was to increase the performance characteristics and reliability of these lines by developing improvements in design, construction and/or usage.

A four step approach was initiated to evaluate the operating parameters and functional integrity of the existing hardware. It was as follows:

A. Review flex line detail, assembly and installation drawings and specifications, including shop fabrication prints and procedures.

B. Review (on-site) the installed flex lines as used both in the swing arm test fixtures at Huntsville and the actual launch umbilical tower at Cape Kennedy.

C. Review all Unsatisfactory Condition Reports generated by NASA and all AMETEK/Straza Inspection Reports which describe any type of V. J. flex line failure. Detailed inspection of launch movies.

D. Correlate the information generated in the first three steps into a meaningful image of what is needed to improve the existing design of vacuum jacketed flex lines used at the Saturn launch facility.

On the basis of this hardware evaluation, the product review was initiated. Thirty-one manufacturers of flex hose, some involved in cryogenics, were contacted by letter and telephone. No advances in technology were found in responses to these contacts, and it was established that the V. J. flex lines in use at the Saturn launch facilities are representative of existing state-of-the-art hardware.

Vendors of specialty products which could serve as the basis for design improvements were contacted and their products evaluated. In some cases, facilities of vendors were inspected and the design problems were discussed with engineering staffs. These contacts were productive in the generation of methods, materials technology and processes which served to confirm the feasibility of several design ideas.

The first step in the approach to improved flexibility was to determine the relative contributions of what were considered to be the two major influences on resistance to bending, (a) the bellows and (b) the braid. A preliminary test indicated that the braid is a slightly more significant factor in overall line flexibility than the bellows in the case of a typical flex hose.

A preliminary test was also conducted to determine the bending moment created by pressurized bent flex lines and also to find the resistance to bending when pressurized. The results showed that the single wall braided flex hose was approximately ten (10) times as stiff when pressurized to 50 psig as when unpressurized. Since braid friction could be a major operating factor and it is not practical to make analytical calculations, it was proposed in the Phase II Test Plan that further detailed testing evaluation be done.

The types of damage suffered in service by the lines demonstrated the need for more rugged assemblies. Damage ranged from small (.030 inch deep) dents in the tips of the convolutions of the outer jacket to complete destruction of a V. J. line by ripping into two (2) separate pieces. However, the predominant failure mode was a combination of shock load and abrasion applied on the outer jacket surface in such a manner as to produce separation and tearing of the braid along with flattening of outer jacket bellows convolutions over an area ranging from three (3) to twelve (12) square inches. Loss of vacuum integrity through leaks thus generated in the outer jacket bellows was common.

A stronger bellows is fairly simple to attain if a larger bellows diameter and higher weight can be tolerated. An increase in bellows material thickness when accompanied by an increase in convolution height can result in a stronger assembly which still has comparable flexibility.

A more easily repaired flex line assembly can be attained by making the outer jacket braid removable. Since the braid on the outer jacket carries no pressure loads and serves solely as a protective device over the bellows, a braid clamp attachment would suffice. Making this change from welded attachment to clamping would expedite repairs to both braid and outer jacket bellows and in many cases make the difference between field repairable damage and that which must be sent to the manufacturer for correction.

With the foregoing in mind, the approach was taken to generate design ideas which would effect (a) stronger bellows, (b) better protection for bellows, (c) more easily repairable lines and (d) more flexible lines.

The major new technology proposed to effect the foregoing was (a) energy absorbent bumper material to be placed on the outer jacket bellows, (b) easily removable braid on outer jackets, (c) either lighter braid or no braid on the outer jackets (the energy absorbent material replacing the outer braid), and (d) generation of pressurized line flexibility data upon which to base flex line lengths and routing in usage such as the swing arms on the launch Complex 39 umbilical tower.

Material research for energy absorbers suitable for use external to the flex lines was undertaken and several possible candidates chosen. (a) Polytetrafluorethylene (Teflon), (b) Nylon, (c) Molded silicone rubber and (d) Room Temperature Vulcanizing (RTV) silicone rubber.

Preliminary design work was accomplished for a removable braid fastening configuration using a band clamping arrangement.

The Phase II program proposal included as its major item a test plan designed to verify the relative ruggedness of flex lines with and without the various energy absorbent materials, verify usage of removable braid attachments, determine bending loads (line flexibility) under pressure and determine the affect of the energy absorbent materials on flexibility. After approval of this test plan and the test procedures specific to each test, Phase II activity commenced. All tests including environmental, (salt spray, high temperature and low temperature exposure) were conducted, witnessed, documented and reports written. Analysis of the Phase I and Phase II program goals and test results led to the following conclusions and recommendations.

## Conclusions

A. The concept of using a strip of energy absorbent material placed circumferentially about the outer jacket of a flex hose between the braid and the bellows is feasible, producible and can be of significant value in reducing external damage of the type most commonly encountered at Launch Complex 39; that is damage caused by impact during handling and installation. Silicone rubber affords a greater degree of impact resistance than Teflon or Nylon. Teflon resists simulated launch blast conditions (1400$^{o}$F for 10 seconds) without damage. Nylon, Molded Silicone Rubber and RTV Silicone Rubber suffered varying degrees of damage. Further development of the energy absorbent materials and configurations can lead to a basic advance in reliability of V. J. flex lines of all types. Standards of impact resistance should be specified when flex hoses are procured. These standards should be based on anticipated service and handling conditions. Future procurement of flex hoses for use such as that at Launch Complex 39 at Cape Kennedy should specify an energy absorbent material between braid and outer jacket bellows. The energy absorbent material should be euqivalent to cured-in-place RTV silicone rubber, and preferably clear. The thickness of the energy absorbent material should depend on impact resistance required. Impact resistance criteria should be related to specific anticipated handling loads. A test machine should be used in qualification of impact resistance.

B. Short, large diameter flex hoses should be avoided where possible to avoid high stress conditions at the connections when such lines are pressurized and subject to motion. The line length and pressure are the critical factors and should be carefully considered on new installations.

C. On vacuum jacketed flex hoses such as those in use at Launch Complex 39, the outer jacket braid should be removable for field inspection and possible field repair. A braid angle of 45$^{o}$ to 55$^{o}$ should be specified for all braid used on flex lines.

D. Multiple ply bellows design has no value as a means of increasing reliability based on the failure modes (impact and abrasion damage) observed on flex hoses at Launch Complex 39 since they are non-repairable and the same degree of flexibility can be achieved by higher bellows convolutions.

E. Maximum allowable bending loads should be specified for procurement of flex lines, both pressurized and un-pressurized where applicable to installation and service conditions. Bending loads for specific hoses should be based on allowable connection point stresses with installation convenience taken into consideration.

F. Personnel involved in handling flex lines should be instructed in proper handling methods to avoid hardware damage. Handling procedures cautioning personnel to use care with flex lines should be established to avoid dropping tools on lines, exceeding minimum bend radii, etc.

Recommendations

A. A minimum wall thickness of outer jacket bellows should be increased from .010 inch to .016 for all sizes and types of flex hoses. Reliability would be greatly increased by this change on existing as well as hardware planned for future use.

B. Complete motion studies should be made of flex hoses now in use on the Launch Umbilical Tower at Complex 39 as well as any future systems planned. This study would optimize flex hose lengths, bending modes and also take advantage of information developed by this study to avoid damage to lines at launch operations and reduce attachment point loading.

C. Further study of vacuum jacketed flex hose design should be made to evaluate: (1) possible inner line braid design improvement, (2) possible replacement of outer jacket braid with energy absorbent materials, (3) improvement of braid attachment methods and (4) fatigue life of vacuum jacketed flex hoses in various bending modes.

3.0 FINAL REPORT

3.1.0 PHASE I TECHNICAL REPORT

3.1.1 Hardware Evaluation

3.1.1.1 Introduction

At the beginning of the program, a four step approach was initiated to evaluate the design, construction, specification requirements, operating parameters and functional performance of the vacuum jacketed flex lines in use on the launch umbilical tower swing arms for the Saturn V vehicle. It was determined that the scope of the investigation should include all design, functional and environmental factors with special emphasis on line flexibility and failures of all types. The four steps were as follows:

A. Review V. J. Flex Line specifications, shop fabrication drawings, test procedures and installation drawings to determine details of line design and construction in relation to operating criteria originally established by NASA.

B. Make on-site inspection of V. J. Flex Lines installed on umbilical tower swing arms at Marshall Space Flight Center and at the Vehicle Assembly Building at Kennedy Space Center. Review the installed geometry of these lines and their disconnect motions. Discuss handling, installation, testing and maintenance problems with the personnel involved with these operations in the field.

C. Review all Unsatisfactory Conditions Reports generated in the field and all AMETEK/Straza Inspection Reports on line failures of all types to serve as the basis of a reliability analysis.

D. Translate the information gathered in the first three steps into specific problems for possible solution in the Product Review and Design Phase efforts of the program.

The following information and conclusions were generated as a result of the foregoing approach:

3.1.1.2 Specification Requirements

Two basic types of V. J. Flex Lines are involved in this study: (a) Cryogenic liquid propellant transfer lines used for $LO_2$ and

and $LH_2$ flow into vehicle and (b) $GH_2$ vent lines used to transfer gaseous hydrogen from the vehicle. The basic NASA documents controlling design, fabrication and testing of these lines are as follows:

| | | |
|---|---|---|
| 75M09793 | $LO_2$ Transfer | Arm #1 |
| 75M06519 | $LH_2$ & $LO_2$ Transfer | Arms #1 & #4 |
| 75M09783 | $GH_2$ Venting | Arms #5 & #7 |
| 75M05865 | $LH_2$ & $LO_2$ Transfer | Arms #6 & #8 |

Conforming to these basic procurement specifications are ten (10) propellant transfer flex lines which have an evacuated annulus at room temperature and five (5) venting flex lines which are pressurized to 5 psig in the annulus with $CO_2$ at room temperature. All of the lines are double wall metallic bellows design. The bellows are predominantly type 316L CRES (some are type 321 on inner lines) ranging in thickness from .010 to .020 inch. All bellows are single ply construction, annular corrugations (as opposed to spiral) and hydraulically formed. The propellant transfer lines employ radiation shielding (aluminized mylar or fiberglass and aluminum foil) to reduce heat transfer and molecular sieve gettering material (charcoal or zeolite) to aid long term vacuum retention in the annular space. The vent lines use neither of the foregoing since heat transfer is not as important a factor with gas that is expelled from the vehicle.

The individual acceptance tests consisted of proof pressure, leakage and thermal shock which were done at the manufacturers facility (AMETEK/Straza). The qualification tests were performed by the Boeing Company at the MSFC LC39 GSE test facility. The tests were proof pressure, leak, thermal shock, flex cycle, vibration and burst pressure. It is noted here for future reference that the flex cycling tests were conducted without line pressurization.

3.1.1.3 On-Site Evaluation

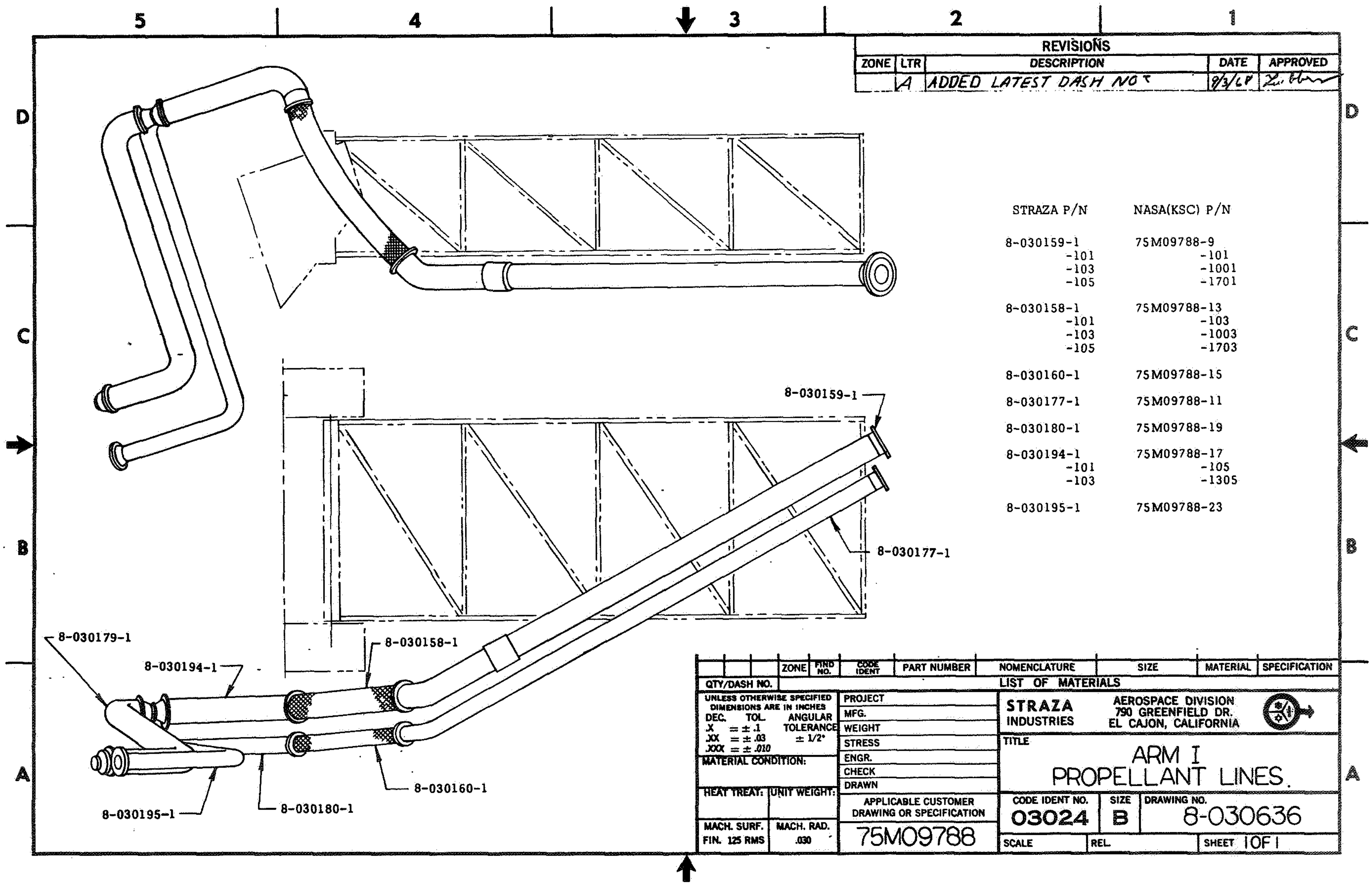
Testing, maintenance and assembly personnel were interviewed to obtain first hand information on line flexibility, damage and handling characteristics. No problems were found related to unpressurized line flexibility in handling, testing or installation. Some evidence was found of lack of ruggedness in lines. Maintenance problems were oriented toward accessory components such as burst discs and thermocouples. It was noted that during installation on swing arms, the flex lines are exposed to rough handling, bumps, scraping on structure and other potential hazards which are virtually unavoidable. The need for more rugged outer jacket construction on flex lines became obvious at this point.

The flex lines are installed on the swing arms in the position as shown on the accompanying AMETEK/Straza drawings 8-030636, 8-030639, 8-030640, 8-030643, 8-030645 and 8-030647. It may be noted that in some cases flex lines appear to be just long enough to accommodate the (approximately $100^{\circ}$) arm motion (see 75M09788-13 and 75M09788-15 on Arm 1). In other cases such as the 75M09667-5 and 75M09667-7 lines on Arm 5, there appears to be significantly more length of flex line than necessary for the retraction motion. In addition, there appear to be situations where the choice of flex line usage versus gimbal articulated hard line usage is questionable. One case in point is the 75M07823-9 lines used on Arm 6 for vehicle interface motion compensation. Pressurization prior to launch makes these flex hoses much stiffer than a gimballed hard line would be. The loads on line mounting structure are thus greater than necessary. Examination of line geometry as installed and in motion during launch was made by studying motion pictures of the MSFC swing arm qualification testing program as well as actual launch. It was noted that impact forces on some lines such as 75M09304-7 on Arm 7 are severe during retract at launch.

Based on the foregoing information it was concluded that (a) more rugged lines are needed, (b) that line re-routing might in some cases reduce some damage, (c) that unpressurized line flexibility during installation is not a problem, (d) that pressurized line flexibility during launch may be a problem and (e) that the choice of flex lines versus gimballed hard lines is in some instances questionable.

3.1.1.4 Review of Conditions and Failures

All AMETEK/Straza Inspection Reports for flex lines returned for repair and all flex line Unsatisfactory Condition Reports generated at KSC and MSFC were collected and analyzed. These reports are part of the Unit Docket data compilation created during the study program. A total of twenty-six (26) line failures are described in these records; some are due to damage or failure in a single location on the line and others involve multiple location damage and failure on a given line. Of the twenty-six line vailures, twenty-two were due to externally applied shock and/or abrasion loading, one was due to excessive pressurization, one was a fabrication defect, one was a material defect and one was of unknown origin. None of these failures occurred during filling or venting or during launch.




AMETEK/Straza Drawing 8-030636

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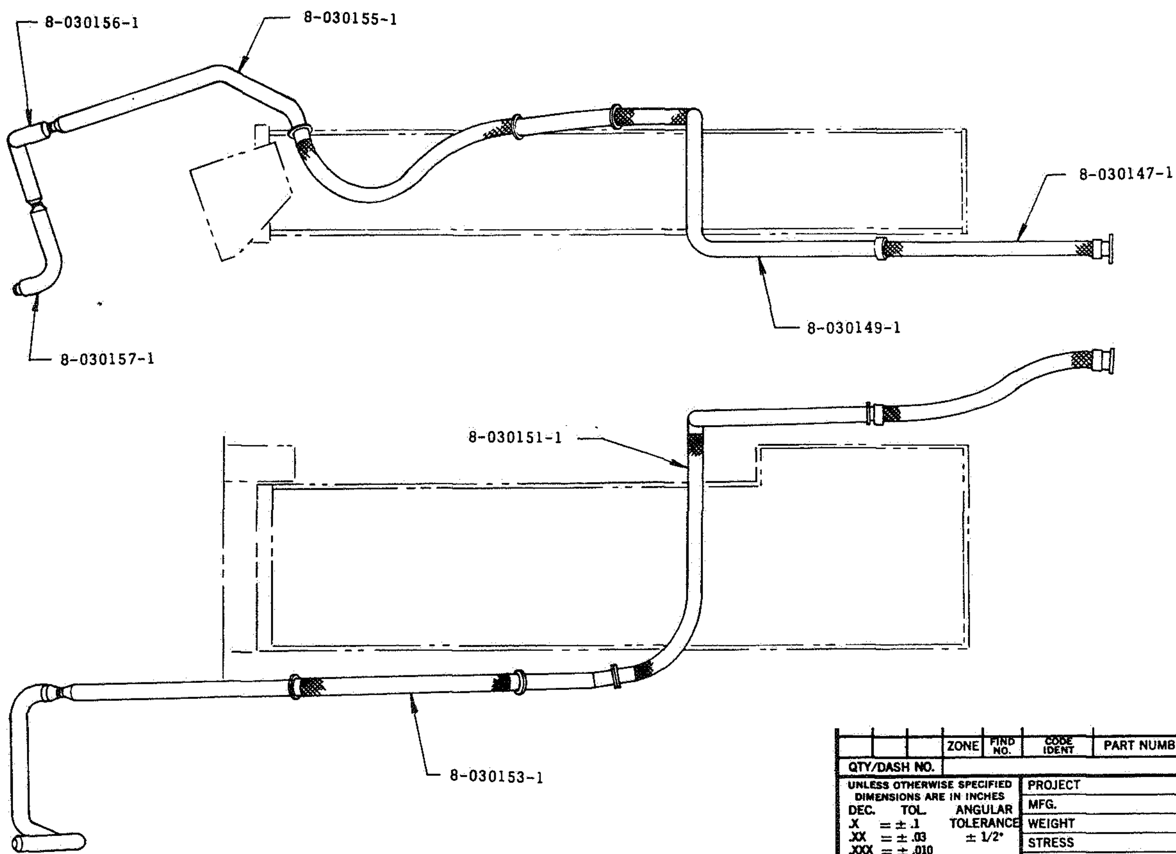


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| 8-030149-1 | 75M14016-7 |
| 8-030151-1 | 75M14016-9 |
| 8-030153-1 | 75M14016-11 |
| 8-030155-1 | 75M14016-13 |
| 8-030156-1 | 75M14016-15 |
| 8-030157-1 | 75M14016-17 |

| QTY/DASH NO. | ZONE | FIND NO. | CODE IDENT | PART NUMBER | NOMENCLATURE | SIZE | MATERIAL | SPECIFICATION |
|---|---|---|---|---|---|---|---|---|

LIST OF MATERIALS

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
DEC. TOL. .X = ± .1, .XX = ± .03, .XXX = ± .010
ANGULAR TOLERANCE ± 1/2°
MATERIAL CONDITION:
HEAT TREAT: | UNIT WEIGHT:
MACH. SURF. FIN. 125 RMS | MACH. RAD. .030

PROJECT / MFG. / WEIGHT / STRESS / ENGR. / CHECK / DRAWN

APPLICABLE CUSTOMER DRAWING OR SPECIFICATION: 75M14016

**STRAZA INDUSTRIES**
AEROSPACE DIVISION
790 GREENFIELD DR.
EL CAJON, CALIFORNIA

TITLE: ARM 4 PROPELLANT LINES

| CODE IDENT NO. | SIZE | DRAWING NO. |
|---|---|---|
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SCALE | REL. | SHEET 1 OF 1

AMETEK/Straza Drawing 8-030639

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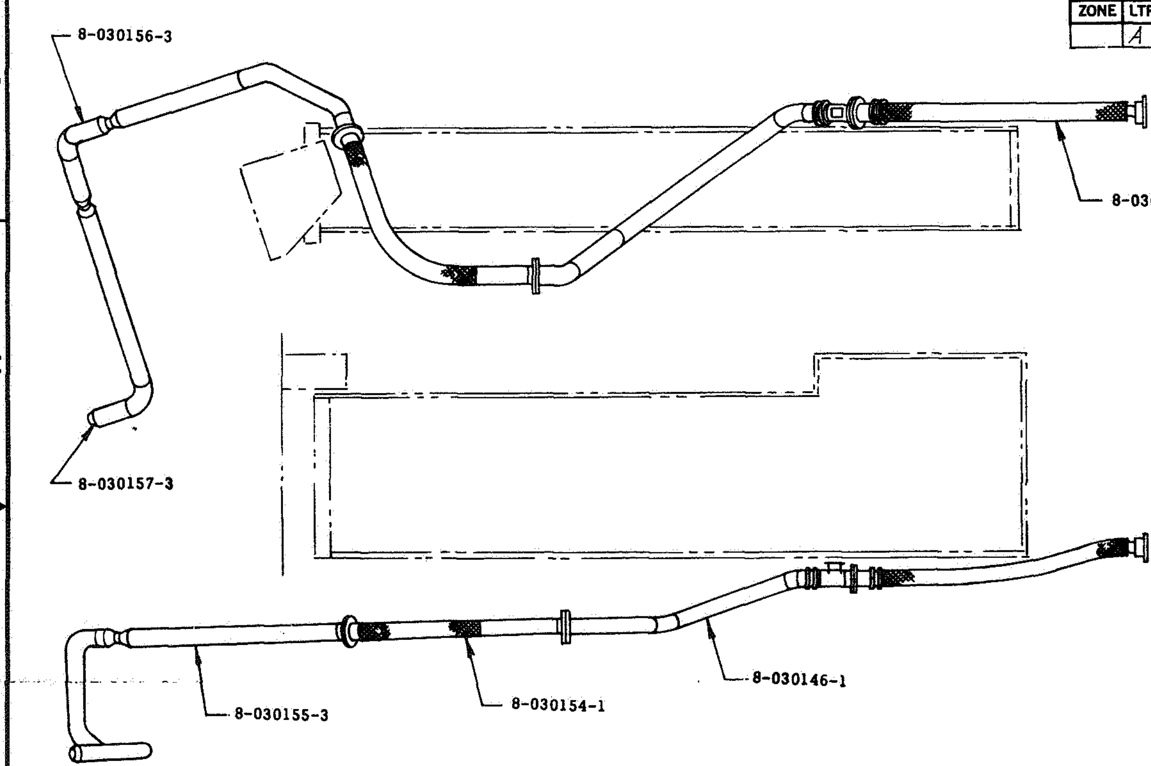


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| 8-030146-1, -101, -103, -107 | 75M14015-7, -303, -703, -1603 |
| 8-030154-1, -101, -103, -105 | 75M14015-9, -105, -1005, -1705 |
| 8-030155-3, -101, -103 | 75M14015-11, -107, -1307 |
| 8-030156-3, -101, -103 | 75M14015-13, -109, -1309 |
| 8-030157-3, -101, -103 | 75M14015-15, -111, -1311 |

| QTY/DASH NO. | ZONE | FIND NO. | CODE IDENT | PART NUMBER | NOMENCLATURE | SIZE | MATERIAL | SPECIFICATION |
|---|---|---|---|---|---|---|---|---|

LIST OF MATERIALS

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
DEC. TOL. ANGULAR TOLERANCE
.X = ± .1 ± 1/2°
.XX = ± .03
.XXX = ± .010

MATERIAL CONDITION:

HEAT TREAT: UNIT WEIGHT:

MACH. SURF. FIN. 125 RMS | MACH. RAD. .030

PROJECT
MFG.
WEIGHT
STRESS
ENGR.
CHECK
DRAWN

APPLICABLE CUSTOMER DRAWING OR SPECIFICATION: 75M14015

STRAZA INDUSTRIES
AEROSPACE DIVISION
790 GREENFIELD DR.
EL CAJON, CALIFORNIA

TITLE: ARM 4 PROPELLANT LINES

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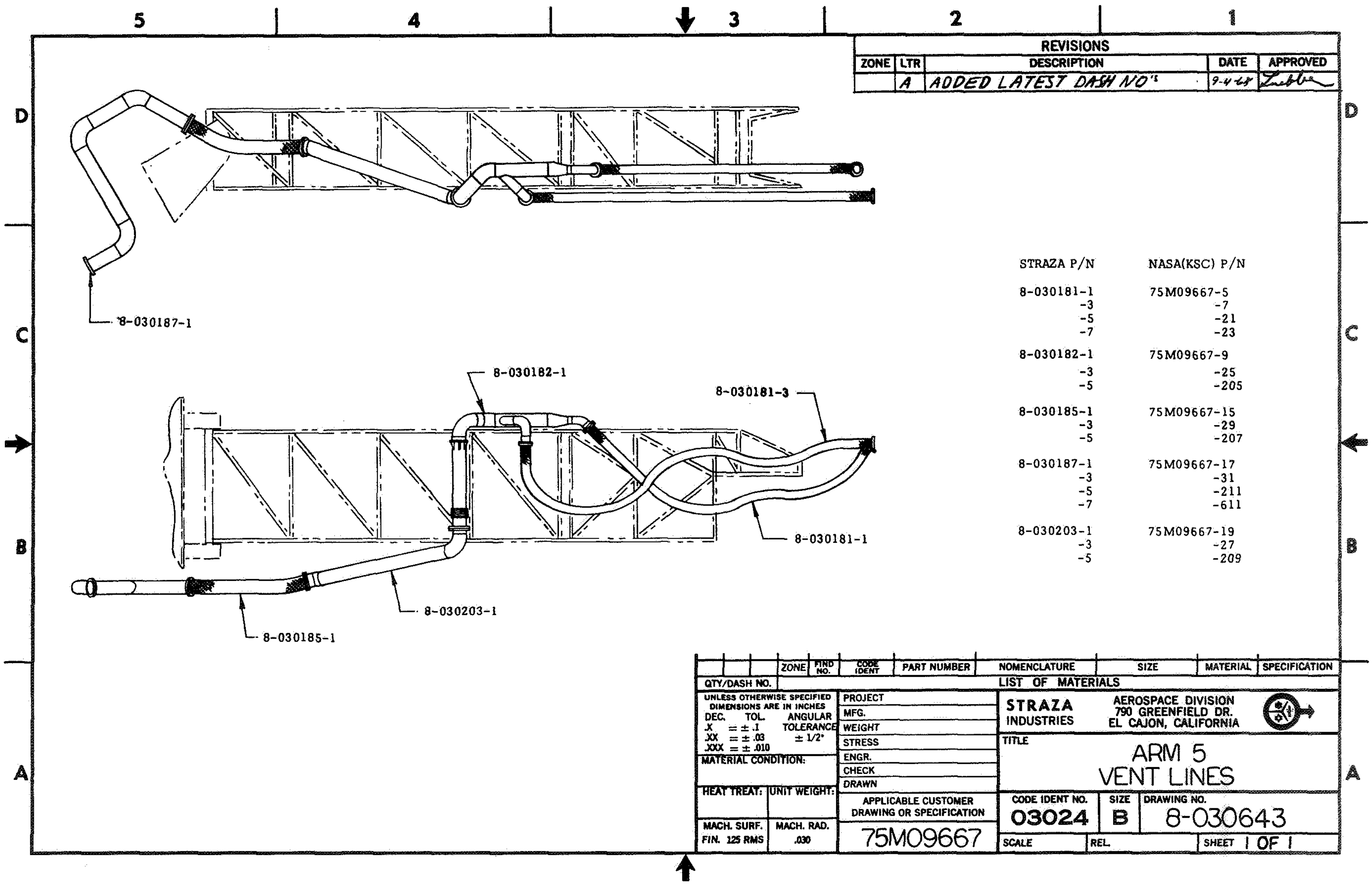
SCALE | REL. | SHEET 1 OF 1

AMETEK/Straza Drawing 8-030640

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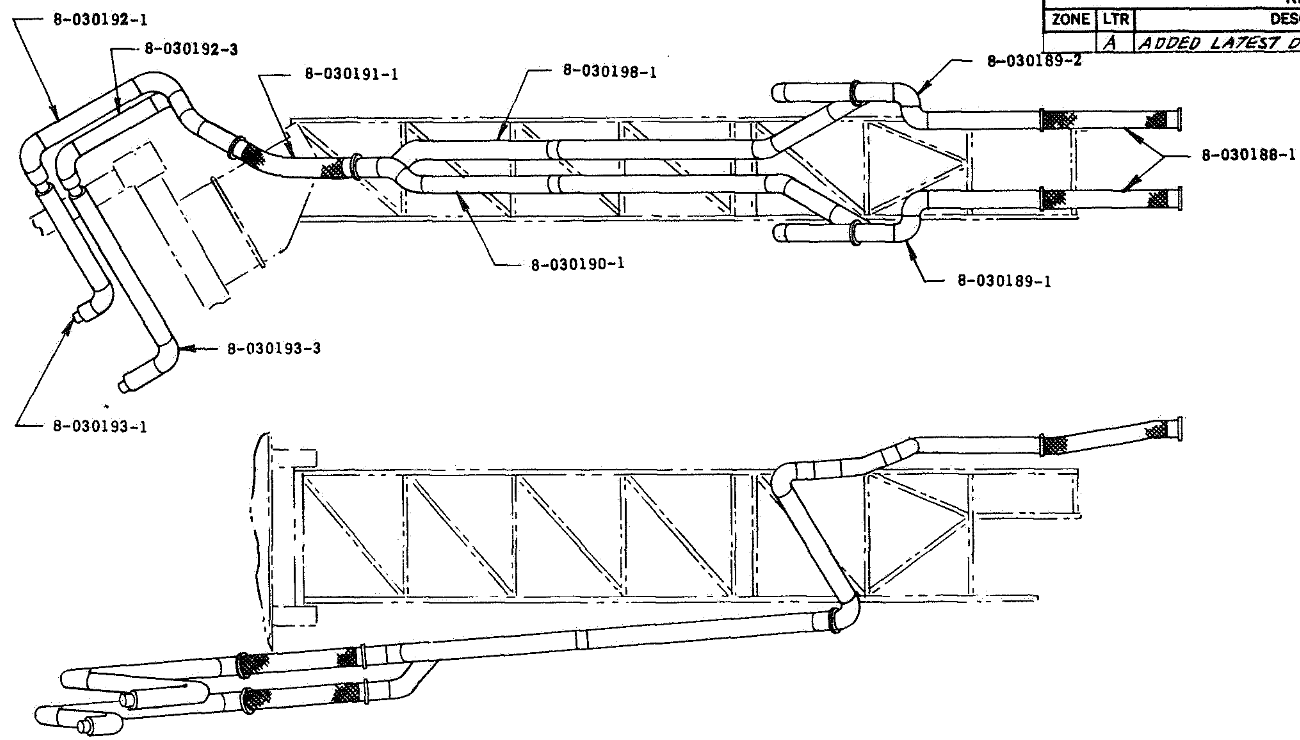


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| 8-030189-2,-102,-104 | 75M07823-12,-704,-1604 |
| 8-030190-1,-101,-103,-105 | 75M07823-13,-105,-1605,-1705 |
| 8-030198-1 | 75M07823-15 |
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| 8-030192-1 | 75M07823-19 |
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**REVISIONS**

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| | A | ADDED LATEST DASH NO'S | 9-4-68 | [signature] |

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LIST OF MATERIALS

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
DEC. TOL. ANGULAR TOLERANCE
.X = ± .1
.XX = ± .03 ± 1/2°
.XXX = ± .010

MATERIAL CONDITION:

HEAT TREAT: | UNIT WEIGHT:

MACH. SURF. FIN. 125 RMS | MACH. RAD. .030

PROJECT | MFG. | WEIGHT | STRESS | ENGR. | CHECK | DRAWN

APPLICABLE CUSTOMER DRAWING OR SPECIFICATION: 75M07823

STRAZA INDUSTRIES — AEROSPACE DIVISION, 790 GREENFIELD DR., EL CAJON, CALIFORNIA

TITLE: ARM 6 PROPELLANT LINES

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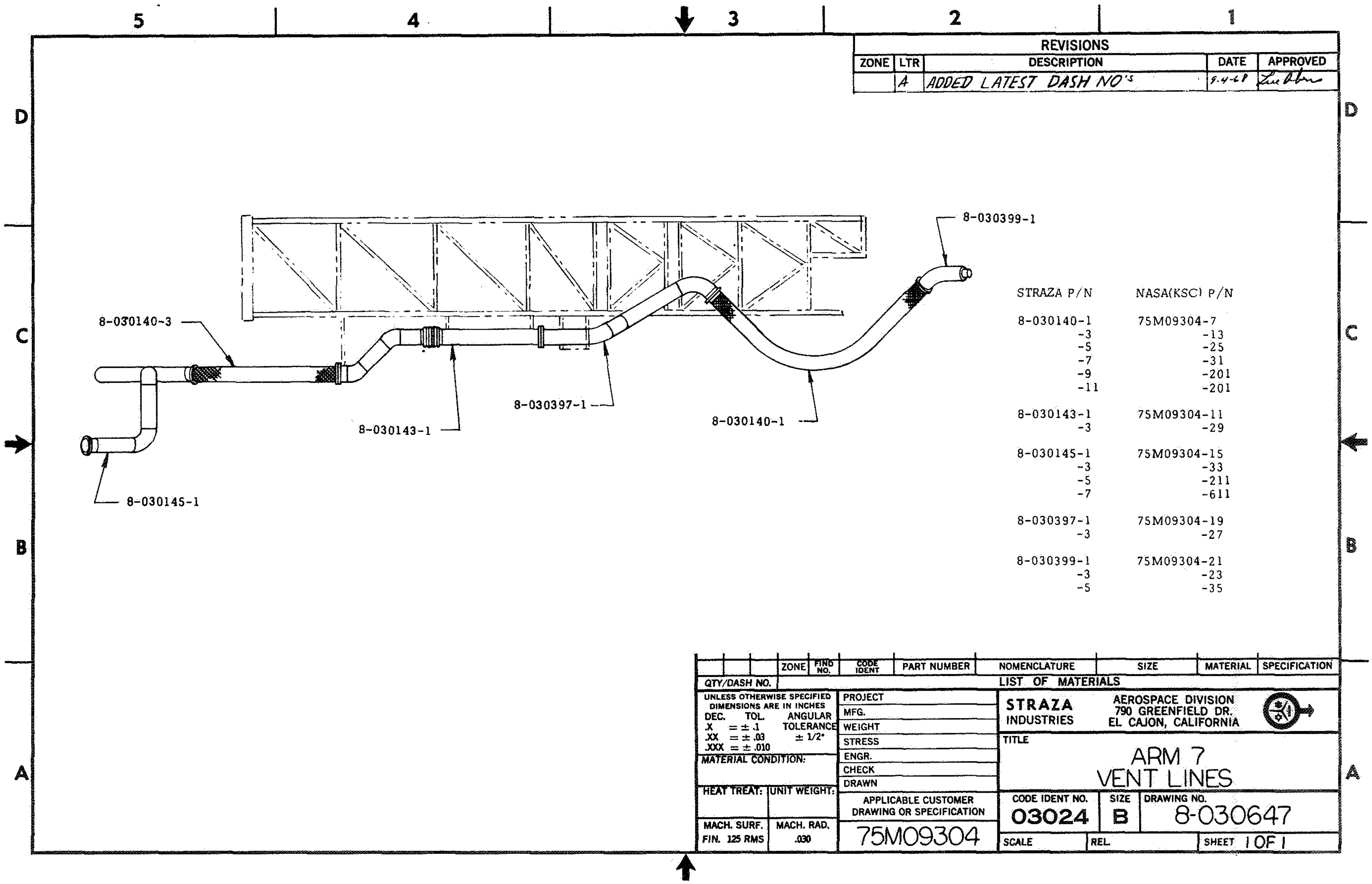
SCALE | REL. | SHEET 1 OF 1

AMETEK/Straza Drawing 8-030645




AMETEK/Straza Drawing 8-030647

The predominant type of failure involved torn braid strands on the outer jacket, dented bellows convolutions and loss of vacuum integrity. Extend of damage ranged from a few broken braid strands with .010 inch dents in a convolution to a line which had been completely torn into two pieces. Some damage was caused by failure of accessory components such as burst disc leakage. Typical of this type of damage is the case of a slow leak in a burst disc causing the annular space between inner line and jacket to fill with liquid air when inner line is filled with $LH_2$. When the line is allowed to warm, the gas in the annular space expands faster than it can escape through the opened burst disc and the inner line collapses under the excessive external pressure. However, since this study program considers burst disc improvement as a separate task, this type of failure is not pertinent to the flex line portion.

To summarize the analysis of flex line failures the following conclusions were drawn from the evidence studied.

A. External damage to outer jackets must be reduced in order to improve flex line reliability.

B. The outer line braid and bellows are the most vulnerable components. (See photograph on the following page.)

C. New handling procedures or re-routing of lines would not be a significant improvement.

D. The reliability of existing flex lines, based on the performance of eighty-one (81) units in use is .6790.

3.1.1.5 Reliability Program

The Reliability Analysis forms the basis of the Reliability Program. The program outline is:

I. Establish Reliability of Existing Hardware

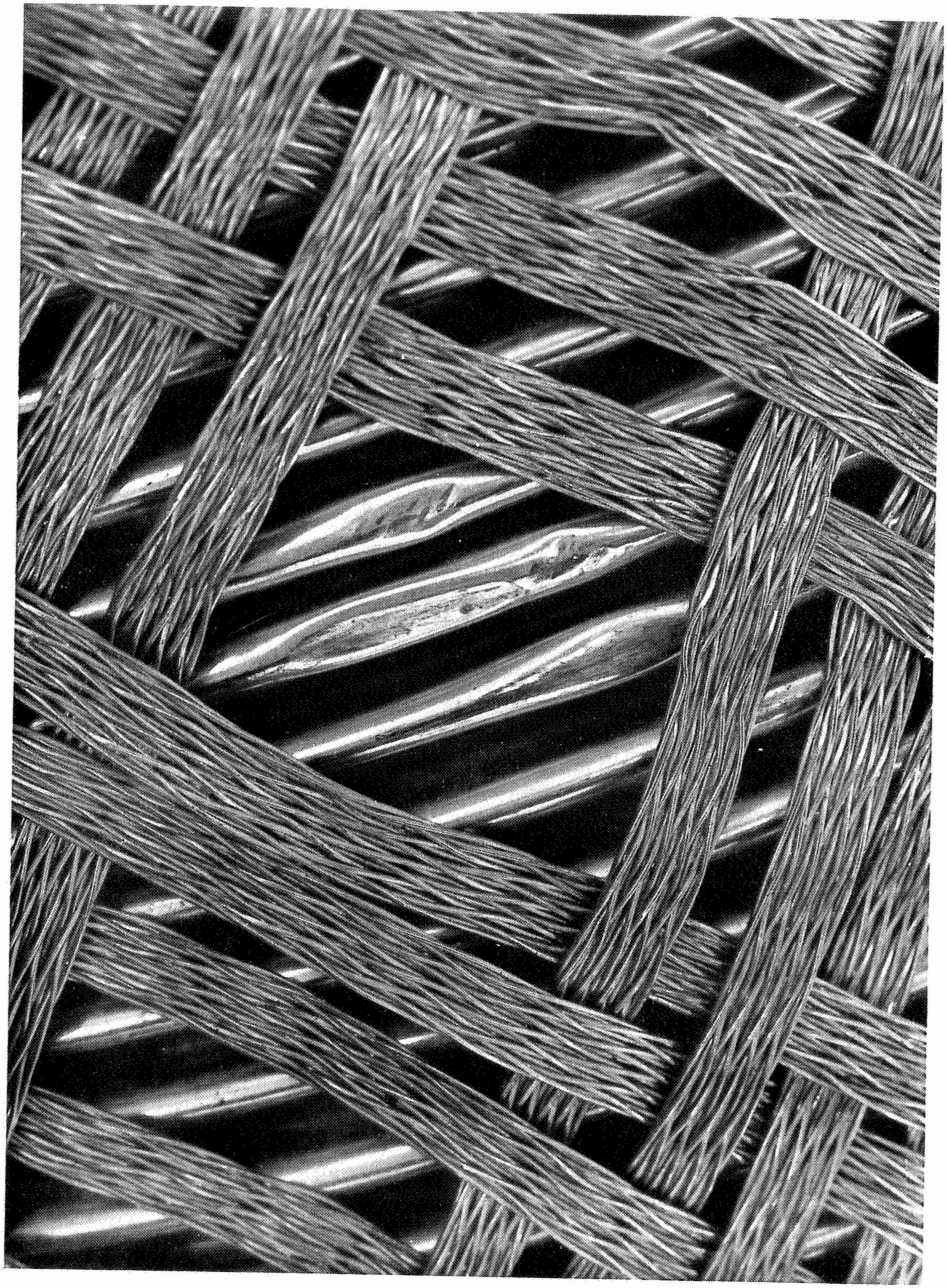
   (a) Usage data, reports, rejections, failure analysis.

II. Establish Reliability of State-of-the-Art Hardware

   (a) Vendor contact, industrial usage information.

III. Establish Reliability goal for new hardware

   (a) Base goal on projection of design



Vacuum-Jacketed Flex Line Damage Incurred At Launch Complex 39

IV. Evaluate Reliability of new hardware

(a) Phase II test results

The foregoing Hardware Evaluation established that the reliability of existing hardware is .6790. It is found in the following Product Review that no hardware presently in use would have a significant impact on this level of reliability. Thus the state-of-art is assumed to be the same order of reliability as the existing hardware in use at Launch Complex 39. Step III and Step IV in the above outline will be included in the Phase II effort as the final steps of Reliability Program.

3.1.1.6 Data Correlation

The purpose of the Hardware Evaluation task was to determine specific weaknesses in the design, construction and/or function of the flex lines under study. Correlation of all the data gathered during this initial phase of the program resulted in the following conclusions:

A. The NASA specifications governing flex line design were non-definitive regarding ruggedness. An example of this is Paragraph 3.4.1 of 75M05865 which states, "Each assembly shall be built to withstand the strains, shocks, vibrations and other conditions incident to the delivery, installation and service". If ruggedness test data had been available, more specific criteria could have been established.

B. No specific written handling procedures were made available to personnel involved in testing, inspecting and installation of flex lines. An example of precautions which should be impressed on persons handling such lines is the delicate nature of instrumentation bosses and valves protruding from lines and also the minimum bend radii of the various configurations.

C. Inspection of line motions during launch disconnect revealed some apparent discrepancy between line flexure capacity and actual flexure required in service. An example of this is Arm 5 vent lines 75M09667-5 and -7 which are much longer than motion would dictate.

D. The Unsatisfactory Condition Reports showed the major failure of flex lines was external damage due to shock and abrasion loading. Minor damage which caused many lines to be returned to source for repair could have been precluded by incorporation of some simple shock absorbent material on the outer jacket. Major damage in many cases could have been reduced to minor damage in the same way.

E. The reliability of flex lines is presently very low (.6790). Major improvement of this reliability can only be accomplished with a basic advance in ruggedness design since lack of ruggedness was the major failure mode.

F. Unpressurized hose flexure is apparently not a problem since no installation problems related to hose stiffness were encountered in the investigation.

G. Pressurized line flexure may be a problem since installed geometry in some cases places relatively short flex lines in a position of compensating for relative motion between swing arm and vehicle immediately prior to launch when lines are pressurized and thus very stiff. Further testing and analysis is indicated here.

### 3.1.2 Product Review

The information generated by the Hardware Evaluation phase of the program served as the basis for conducting a Product Review which was aimed at acquisition of industrial technology which could provide solutions to flex line improvement problems. The major efforts of the Product Review were oriented to finding off-the-shelf flex hoses, flex hose accessories or any related products which would improve vacuum jacketed flex line ruggedness, flexure, flexure life, bend radii, ease of maintenance or general strength.

#### 3.1.2.1 Flex Hose

Initially the following manufacturers of flex hose were contacted by mail:

| | |
|---|---|
| American Boa Incorporated | Arrowhead Products |
| Alloy Bellows Incorporated | AMF Thermatool Incorporated |
| Anaconda Metal Hose | Avica Corporation |
| Allied Metal Hose Company | Atlantic Metal Hose Company |
| Flexible Tubing Company | D.K. Manufacturing Company |
| Flexonics | Flexible Metal Hose Company |
| Hallett Manufacturing Co | Gardner Bellows Corporation |

| | |
|---|---|
| Mechmetals Corporation | Keflex Manufacturing Company |
| Marman-Aeroquip | Metal Bellows Corporation |
| Pennsylvania Flexible Metal Tube Company | Stainless Steel Products |
| National Bellows Corporation | Standard Bellows Company |
| Vacuum Barrier Corporation | Standard-Thomson Corporation |
| | Titeflex Incorporated |

Responses from these companies indicated no new developments which would produce flex hoses superior to or different than those presently in use on the Launch Umbilical Tower at Complex 39.

3.1.2.2 Braid

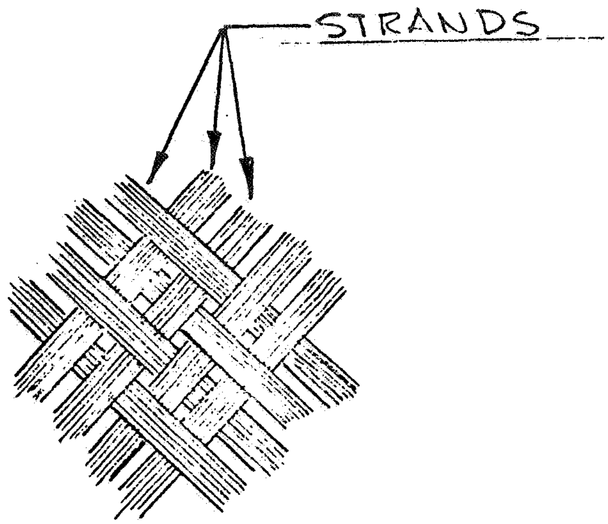
It was next decided to investigate the metal braid since this component of the flex line affects both ruggedness and degree of flexibility. A number of companies manufacture woven tubular wire braid of the type which can be used on flex lines. However, it was found that only the National Standard Company of Niles, Michigan, fabricates braid large enough to be used on lines larger than two (2) inches in diameter, and even this company has only one braiding machine of this size. A trip was made to the National Standard plant in Michigan to evaluate the manufacturing process and to discuss braid design with their engineers. Braid construction presently available is depicted on the following page. For line sizes greater than six (6) inches the "Braided Braid" type of construction must be used since parallel braid simply falls apart when unsupported in the larger diameters. It was further learned that braid angle range is 30° to 65°. The limiting factor is braid manufacturing tooling design. Individual wire diameter size range is approximately .005 inch to .062 inch, depending on number of wires per strand and braid diameter.

It has been the experience of the National Standard Company that a braid angle of 45° is optimum for stabilization of pressurized bellows to prevent "squirm". This is confirmed by the related experience of other bellows manufacturers although no test data was available as proof. No weave pattern deviations from that shown in the braid design figure are available at present.

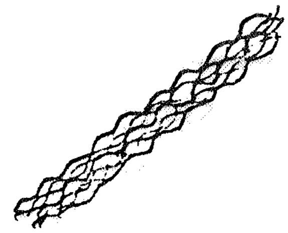
3.1.2.3 Bellows Protective Devices

A search of literature revealed a number of specialty products which might have application to protection of flex hose bellows. These products were evaluated based on the following criteria:

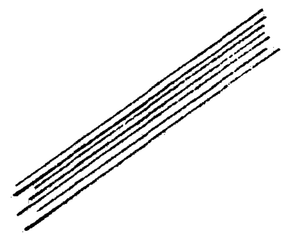
A. Ability to adequately absorb or deflect impact and/or abrasion loads of the magnitude suggested by damage surveyed in the Hardware Evaluation phase.




WEAVE PATTERN

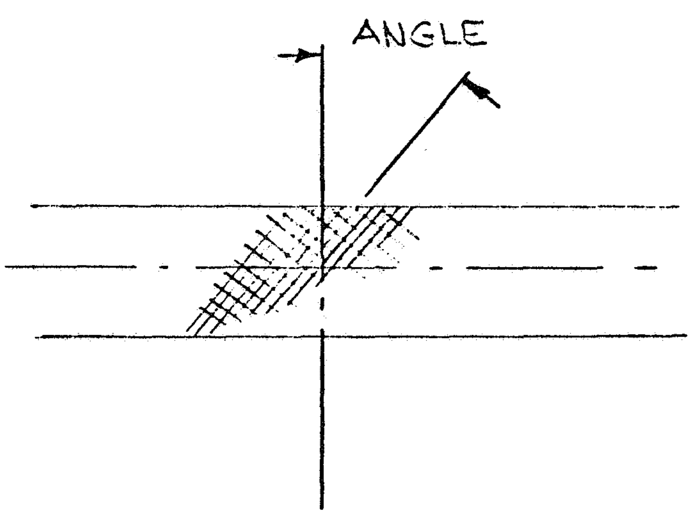


BRAIDED BRAID



PARALLEL BRAID

BRAID STRAND VARIATIONS




BRAID ANGLE

B. Ability to withstand a reasonably broad temperature range in usage estimated at approximately $-65^{\circ}$ to $200^{\circ}F$ long term and $-320^{\circ}F$ to $1400^{\circ}F$ short term.

C. Ability to withstand environmental conditions of salt spray, solar radiation, sand and dust and high humidity without deterioration.

D. Ability to increase or at worst not affect the flexibility of the flex line.

Zippertubing

The Zippertubing Company manufactures a variety of plastic sleeves which are designed as protective covers for electrical wiring. These sleeves have a continuous zipper along their length for easy removal. This product is also available with a fine wire mesh inner liner which would serve as a cushion between a flex hose and the plastic sleeve exterior. The major problem with this type of sleeving would be loss of flexibility. However, it appears to have some merit as a shipping and handling cover which could be removed prior to line installation.

Bentley-Harris Sleeves

A braided sleeve of silicone rubber coated fiberglass is manufactured by the Bentley-Harris Manufacturing Company. It is used in electrical cable coverings but appears to have mechanical strength sufficient to be considered as a replacement for outer jacket braid on flex lines. Abrasion resistance of fiberglass is poor but when coated on an individual fiber level with silicone rubber it might be usable. The temperature compatibility appears to be good, but the closed weave pattern of braid would eliminate convolution visibility in a permanent cover. However, if an easily removable sleeve of this material were used it might be practical. Perhaps a double wall of the material could be assembled over a bellows with removable end clamps as attahcment points.

Carborundum Refractory Fiber

From the standpoints of flexibility, strength and temperature resistance, the various refractory fibers must be considered candidate materials for bellows protection sleeving. However, the difficulty of attaching this material to others and the lack of usage data tend to reduce its usefulness. These materials are primarily intended for high temperature insulation and cryogenic properties are unproven. And again, the lack of convolution visibility would be some problem on permanent covers of these close weave fabrics.

Nalle Plastics Sleeves

A self-gripping sleeve which appears to have some of the geometric construction characteristics of woven wire braid is made by Nalle Plastics. It is, however extruded as an integral part with no individual strands. Even so it might serve as an energy absorber between wire braid and bellows if it were avialable in a high strength, high temperature material. At present however it is limited by the materials which can be extruded in this unique shape. Polyethylene is the only material the manufacturer has used to date.

Shrink-on Plastic Covers

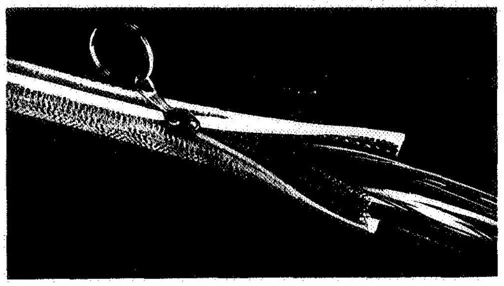
A variety of plastic bellows covers are available from several manufacturers. The concept of a fairly thick (approximately .020 inch) plastic film on the exterior of a bellows would seem to greatly improve its abrasion resistance and possibly its impact load resistance. Two major drawbacks are apparent: (a) greatly reduced flexibility and (b) lack of convolution access for repair or inspection. In addition to these problems there are no presently available high temperature plastics which can be shrunk onto a bellows.

Bellows Convolution Bumper Strips

Several manufacturers are in the business of supplying molded or extruded strips of a variety of plastics materials for use as hole grommets. However, if the "U" shape cross section strips are fitted around the circumference of bellows convolutions, they might be effective in reducing dents and scratches in the bellows. There would be no reduction in line flexibility if the strip were only fitted on every second or third convolution and they would be easily removable (assuming braid is removable on outer jacket.) Thermal range is somewhat limited by materials availability, however Nylon or Teflon might be reasonable candidates.

# NEW PRODUCTS

## Bulletin



**NAME OF PRODUCT** Zippertubing * Type SHX4-FEP10
Shielded Teflon *

**DESCRIPTION** Temperature extreme and abrasion resistant Teflon Zippertubing* with Z-trac which zips on or off quickly. Lined with knitted wire mesh (2-ply or 4-ply) for shielding against electrostatic or R.F. interference, and grounding braid.

**FEATURES** A shielding jacket with excellent dielectric properties, remaining fully functional and flexible under extreme temperature conditions.

Z-trac offers quick zip-on application, zip-off for needed modifications, and holds securely while in use.

Grounding braid is attached the entire length and acts as an RFI seal where the mesh overlaps, preventing possible leakage.

**APPLICATION** Wherever the environmental requirements of exotic conditions cannot be met by other materials. RFI and electrostatic shielding for space application, jet aircraft, and any other installations in extreme environmental conditions, or where chemical protection is required.

**TECHNICAL DATA**

**Physical Properties:**

| | |
|---|---|
| Ultimate Tensile Strength (MD) | 3000 psi |
| Ultimate Elongation (MD) | 300% |
| Tear Strength – propagating (Elmendorf) | 125 gms./mil |
| Area Factor | 12,900 sq. in./lb./mil |

**Chemical Properties:**
Resistant to practically all chemicals except fluorine at temperatures above 200°C, molten alkali metals and certain complex halogenated compounds.

**Thermal Properties:**

| | |
|---|---|
| Melting Point | 500° – 535°F |
| | 260° – 280°C |
| Service Temperature, continuous | –425° to +400°F |
| | –255° to +200°C |

**Electrical Properties:**

| | |
|---|---|
| Dielectric Strength (20 mil) | 1800 volts/mil |
| Dielectric Constant | 2.0 |
| Volume Resistivity | $>10^{17}$ ohm-cm. |

Sizes: 3/4" to 4" in 1/8" increments. Others on request.
Standard putups: 25 and 50 ft.
Wall thickness: 10 mil standard; 15 & 20 mil available.
Color: Clear.

* Registered TM of the Zippertubing Co.
* Registered TM of the DuPont Co.

THE Zippertubing® CO.
Electronics Products Department
13000 S. BROADWAY, LOS ANGELES, CAL. 90061 • 321-3901
494 SO. RIVERVIEW DR., TOTOWA, N.J. 07512 • 256-4980
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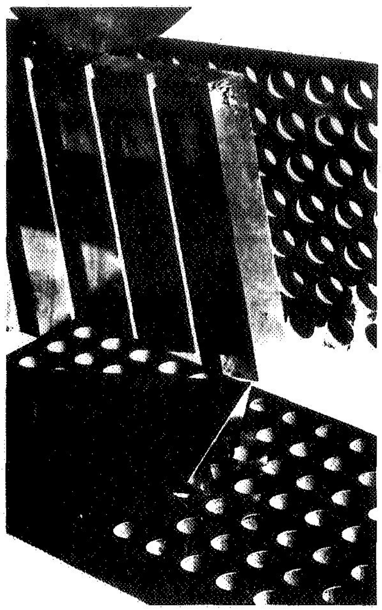
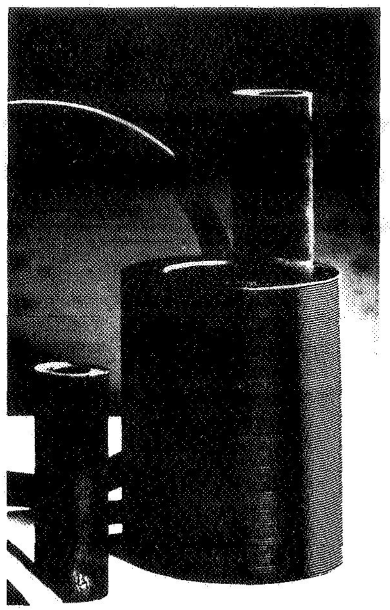


## KT Silicon Carbide®

OUTSTANDING PROPERTIES SCALE

Abrasion Resistance
Corrosion Resistance
Refractoriness

Need greater resistance to wear, heat and thermal shock? Then consider this one. Hardness of KT Silicon Carbide (2740 on Knoop 100 gm scale) far exceeds that of more common wear-resistant materials. And the result is erosion and abrasion resistance that's exceptional. Takes heat to 4200 F (to 3000 F in oxidizing atmospheres). Strength, too, is exceptional—22,800 psi modulus of rupture at 2200 F. Compressive strength at room temperature as high as 150,000 psi. Material is self-bonded, offers high density. Impermeable. Typical uses—valve seats, heat-exchanger tubes, nozzles, bearings, suction box covers for the paper industry.

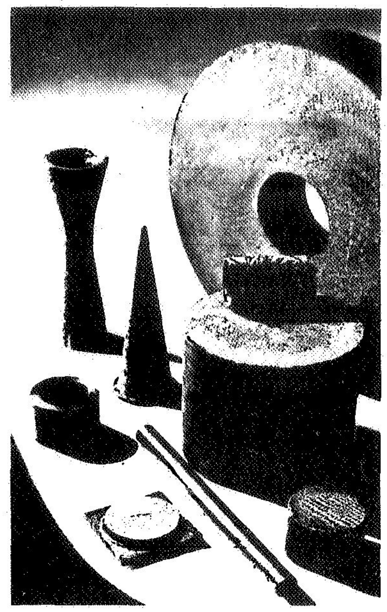


## "HD" Boron Carbide

OUTSTANDING PROPERTIES SCALE

Abrasion Resistance
Corrosion Resistance
Neutron Absorption

"Diamond hard," this one. Harder than the other materials shown here. 2800 on the Knoop 100 gm scale. This hardness, plus density over 99% of theoretical, adds up to the most abrasion-resistant material available in commercial shapes. Another unusual talent—"HD" has high neutron absorption, which recommends it for control rods, shielding in nuclear reactors. What's more, "HD" is chemically stable, nonporous, uniform in composition, yet lightweight (2.52 gms/cc). Material has been diamond ground to tolerances as fine as .0001", with surface finish to 1 RMS. Typical uses—blast nozzles, bearings and seals, sizing rings and gauge blocks, cylinders.



## Carb-I-Tex*

OUTSTANDING PROPERTIES SCALE

Strength
Refractoriness
Thermal Shock

A genuinely new idea in making high-temperature lightweight materials. The name CARB-I-TEX covers a family of materials formed to shape by bonding layers of carbon or graphite cloth, yarn or rope. The bonding agent is elemental carbon. Hoop tensile strengths in excess of 25,000 psi at 4200 F are possible. Virtually immune to thermal shock—no outgassing. Low erosion equals that of the best graphites used for rocket nozzles. And CARB-I-TEX materials are 30% lighter than their solid counterparts. CARB-I-TEX provides the means of building larger and more complex carbon and graphite shapes than ever before possible.

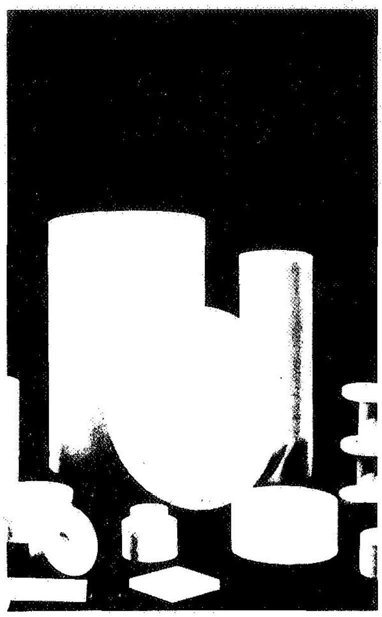
*Patents pending.

## Ready for details?

Just write Dept. MS, The Carborundum Company, Niagara Falls, N. Y. 14302. We'll be glad to send technical bulletins on any or all of the materials described on this and the two preceding pages. Please specify the products that interest you.

CARBORUNDUM

CORROSION, HEAT TO 6000F—WHAT NEXT?

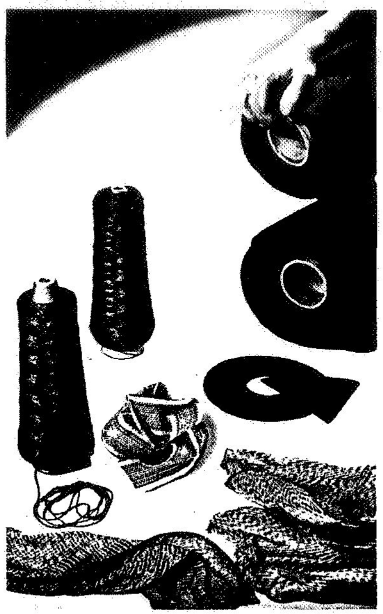


## Boron Nitride

OUTSTANDING PROPERTIES SCALE

Refractoriness
Dielectric Strength
Corrosion Resistance

The advanced Carborundum material that's machinable with ordinary tools. A convenience for prototypes, an excellent jig and fixture material for high-temperature production. Material offers high dielectric strength, even at high temperatures. Lubricity is exceptional. So is thermal conductivity. Resists most corrosive chemicals, is not wetted by molten metals and salts. Standard and High Purity grades available. May be used in inert atmospheres to 5400 F. Solid form resists oxidation to 1800 F. Comes in powders and coatings as well as solids. Typical applications — chemical equipment parts, components for molten-metal pumps, metal crucibles, coil forms, electrical insulators, combustion-chamber liners. Boron nitride powder may be used as mold-release agent, high-temperature lubricant.



## Fiber Forms of Carbon and Graphite

OUTSTANDING PROPERTIES SCALE

Flexibility & Strength
Inertness
Electrical Properties

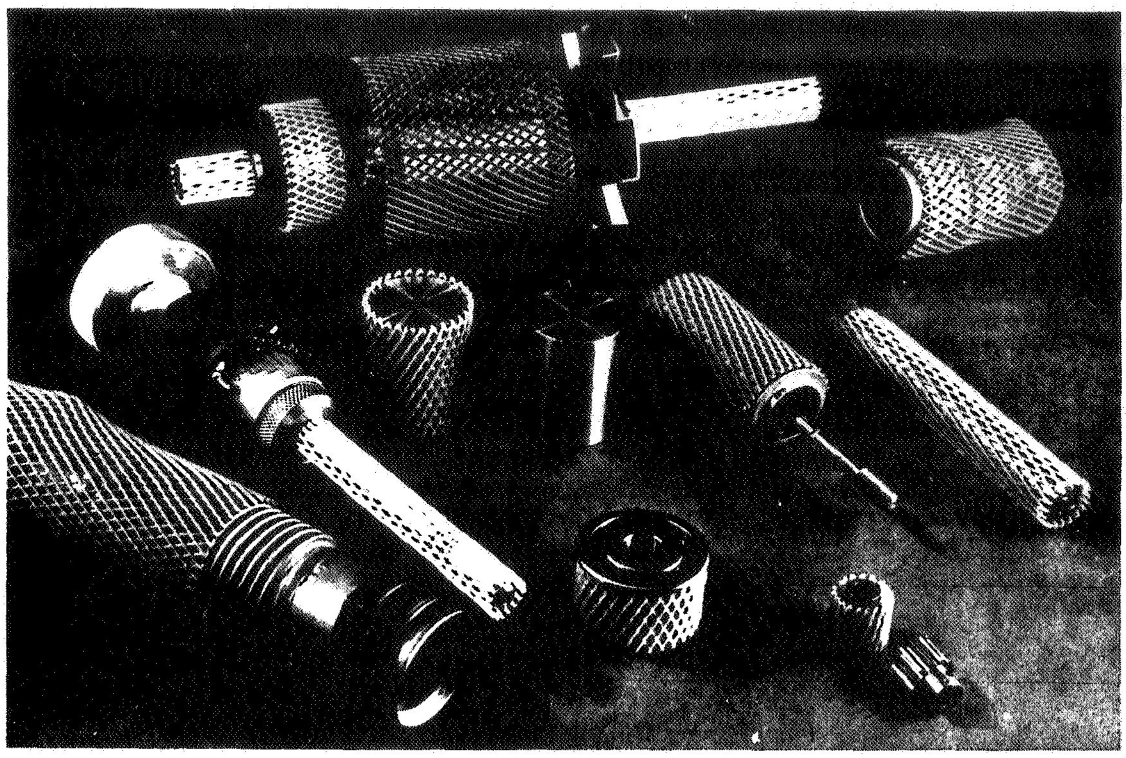
Over 99.9% pure carbon, these fabrics are flexible, yet unbelievably strong. Yarns with specified electrical resistivity from 0.9 to 10,000,000 ohms per foot of length. Chemically inert to virtually all reagents, practically immune to thermal shock. These textile materials can be used to 5700 F. Developed originally for ablative designs for spacecraft, these yarns, felts, tapes and woven fabrics of carbon and graphite now open the door to new concepts in filtration and resistance heating applications such as commercial ovens, high-temperature furnaces, aircraft de-icers, blanket heaters for commercial and military components, sporting equipment and arctic wear.

## Fiberfrax®

OUTSTANDING PROPERTIES SCALE

Thermal Insulation
Refractoriness
Corrosion Resistance

This thermal insulator withstands continuous heat to 2300 F. And that's only the beginning. Low, low thermal conductivity (typical K factor for some forms is less than 1 at 1000 F). Excellent chemical stability and freedom from outgassing. Usable temperature range from cryogenic to 3200 F. That's FIBERFRAX ceramic fiber. A most effective insulation. An excellent gas-filtration medium as well as an excellent gasketing and packing for special applications. Shown are some of the 40 forms offered. Bulk fiber, yarn, rope, tape, cloth, paper, blankets, vacuum-cast shapes, in a sprayable formulation, to name a few. Used to insulate oil-fired furnaces to promote combustion. In heat-treating equipment to promote fast heat-up. As gaskets for viewports in space capsules. Many more applications—the field is wide open.



## Springy Sleeve Forms Self-Gripping Sheath

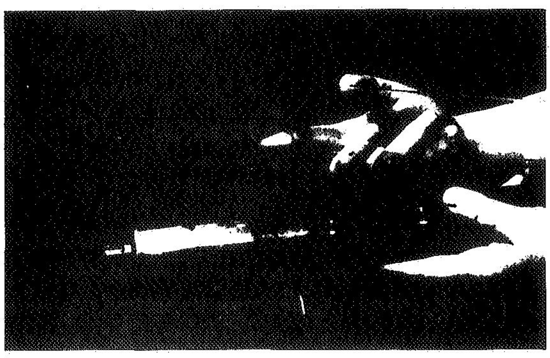
Sleeve is formed by extruding two adjacent layers of parallel polyethylene strips, one layer diagonal to the other. To apply, the sleeve is slightly compressed to increase the diameter and permit a cylindrical part to be inserted. The sleeve tends to stretch to its former length upon release and conforms to the shape of the part, thus forming a protective sheath. Device developed by Nalle Plastics, Austin, Tex.

Nalle Plastics Illustration

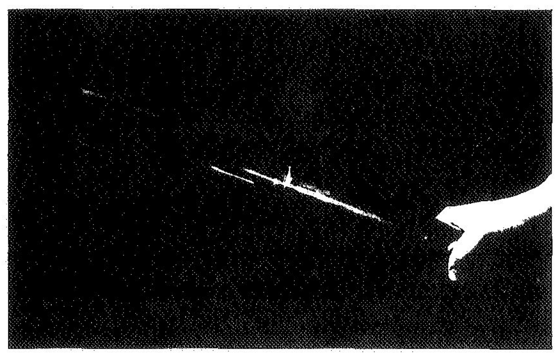
These new roll covers are available in a variety of diameters from 1.25" to 8". Each size will shrink approximately 25% upon application of heat at 220°F. or above. The low temperature required means that the tubing can be applied to wood and plastic without damage to the roll. The table at right shows the sizes of tubing and the roll diameters which each will cover. All sizes are available in lengths up to 10' in one foot increments.

| Nominal Tubing Diameter | Used to cover rolls in this Diameter Range | |
|---|---|---|
| | Min. | Max. |
| 1.25" | 1 | 1.3 |
| 2 | 1.7 | 2.1 |
| 2.5 | 2.1 | 2.6 |
| 3.5 | 2.8 | 3.5 |
| 4 | 3.4 | 4.3 |
| 5 | 4.2 | 5.2 |
| 6 | 4.9 | 6.2 |
| 8 | 6.8 | 8.3 |
| | shrinks to | as supplied |

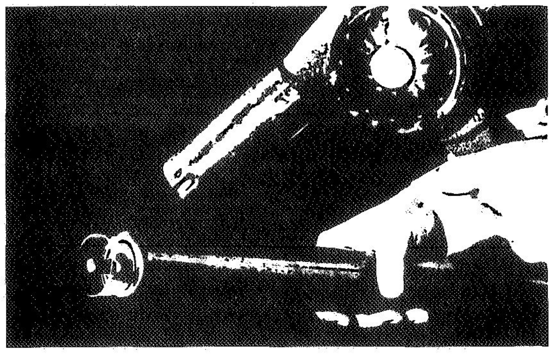
# "TEFLON" FEP SHRINK-FIT ROLL COVERS ARE APPLIED QUICKLY AND EASILY



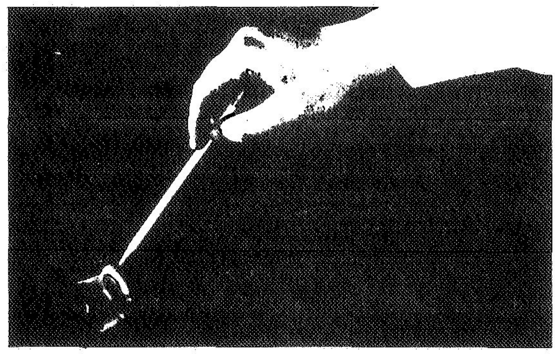
1 First step is selection of the proper diameter of tubing for the roll to be covered. Measure roll diameter and then select tube size from table above. Care should be taken to select the tube diameter that is as close as possible to the diameter of the roll. Roll shown here is a 2" diameter conveyor roll; the tubing used in the 2" nominal diameter size.



2 Shrink-fit roll covers of FEP film can be applied to rolls in a three step process requiring just a few minutes. First the tubing is slipped over the roll. No adhesive system or roll preparation is required. Any existing roll can be covered regardless of the substrate material.



3 Second, heat is applied by use of a commercial hot air gun. A minimum temperature of 220°F. is required for shrinkage. Since the melting temperature is greater than 525°F., there is little chance of damage from overheating during installation. Larger rolls will need to be supported either in a jig or, ideally, on a lathe to provide uniform rotation during tubing shrinkage.

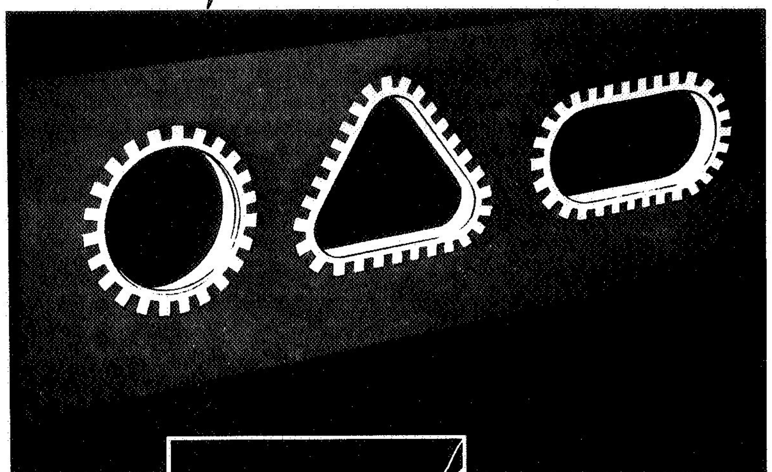


4 Application of heat shrinks the tubing approximately 25 percent, insuring a tight bond to the substrate. The ends are then trimmed at point shown by pencil. Temperature cycling and mechanical working cannot loosen the tubing. A damaged tube or surface can be repaired by removing the damaged material and installing another sleeve. Two or three sleeves can be installed for added durability.

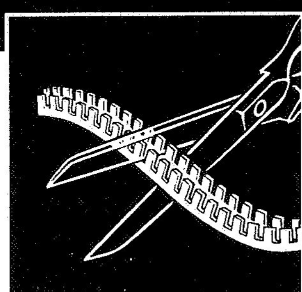
***NOTE: See instruction manual for details***

Shrink-on Plastic Covers Illustration

Weckesser



# MOLDED NYLON FLEXIBLE GROMMET STRIPS



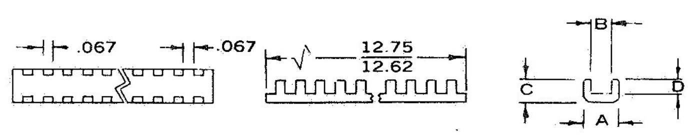
**TYPICAL LENGTH STRIP REQUIRED FOR ROUND OPENINGS**

| Structural Hole Dia. | Grommet Length (Ref.) |
| --- | --- |
| 1.000 | 3.017 |
| 1.125 | 3.407 |
| 1.250 | 3.800 |
| 1.375 | 4.192 |
| 1.500 | 4.585 |
| 1.625 | 4.977 |
| 1.750 | 5.370 |
| 1.875 | 5.762 |
| 2.000 | 6.155 |

■ You always have the right grommet in stock when you rely on WECKESSER FLEXIBLE GROMMETS. They fit any size or shape hole (3/4" diameter and over) and are designed to conform to a very wide range of thicknesses.

Molded from corrosion-resistant natural-color nylon, WECKESSER FLEXIBLE GROMMETS will withstand high temperatures, provide durable protection, meet the specification of MIL-M-20693-A, latest revision. Supplied in 12¾" lengths, they can be cut to any size desired; for larger holes, additional strips can be used. For positive positioning in odd shaped holes, apply Armstrong Type A-12 adhesive cement, or equivalent, to the cleaned edges of the material and grommet.

CONFORMS TO MS-21266




| CATALOG NUMBER | MILITARY STANDARD NUMBER | A | B | C | D | FOR SHEET THICKNESS |
| --- | --- | --- | --- | --- | --- | --- |
| WG-101 | MS 21266-1N | .150 | .056 | .155 | .100 | .015-.052 |
| WG-201 | MS 21266-2N | .175 | .090 | .155 | .100 | .053-.085 |
| WG-301 | MS 21266-3N | .220 | .131 | .155 | .100 | .086-.128 |

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### 3.1.3 Design Phase

#### 3.1.3.1 Design Evaluation

The type of flex lines with which this study is concerned are composed of an inner braided bellows assembled inside of a larger diameter outer braided bellows with spacers between the two. The double wall flexible hose thus formed is designed to be vacuum tight and have a very low order of heat transfer from the outer line to the inner line. The materials of construction are austenitic stainless steel except for the spacers and radiation shielding. Spacer assemblies between inner line and outer jacket maintain the concentricity of the two bellows under all conditions of flexure and are constructed of polytetrafluorethylene. Radiation shielding is used on propellant loading lines only and is aluminized mylar or fiberglass and aluminum foil. On vent lines where heat transfer is not as critical, a $CO_2$ pressurization to 5 psig is in the annulus between lines at ambient temperature. When chilled with cryogen the $CO_2$ condenses onto the cold inner line and a partial vacuum is produced. The propellant loading lines employ a permanent partial vacuum and to aid the longevity of this "hard" vacuum a molecular sieve material of "getter" is placed in the vacuum annulus. The purpose of the getter is to absorb (or more technically, adsorb) any "outgassed" foreign material in the annulus. Thus the only basic differences between lines in this study are the two methods employed to produce and maintain vacuum insulation. Other differences are only minor dimensional, not basic configuration changes.

The major structural components of the flex lines are bellows and wire braid. These two are the only structural members required to be flexible and the radiation shielding on propellant lines is the only other flexible component.

#### 3.1.3.2 Braid Design

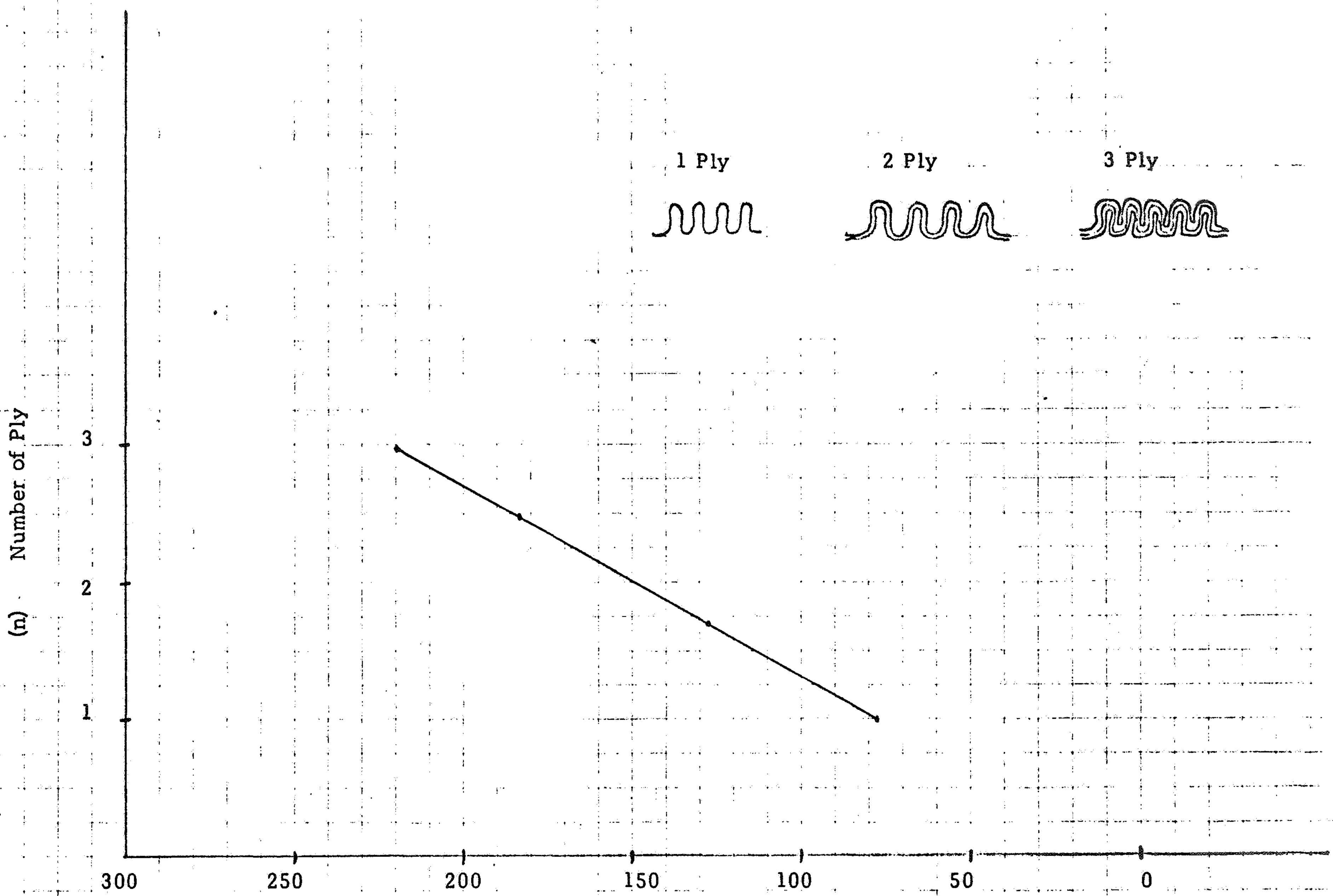
On the flex lines presently in use at Launch Complex 39 the braid around the inner line bellows is used as the pressure end load carrier. The outer jacket braid on these lines serves only as shielding for the relatively light wall (.010) outer jacket bellows. Thus the major design factors needed for inner line braid are (a) axial load carrying strength and (b) flexibility. The outer line braid design factors are (a) ruggedness (b) ability to protect bellows and (c) flexibility. As shown in the Reliability Program section the braid only affords partial protection to the outer line bellows. However the bellows protective devices discussed in the Bellows Protective Devices section are promising and considerable ruggedness improvement is anticipated by their use. The load carrying ability of a tubular braid assembly is reasonably simple to analyze as follows:

| | | | |
|---|---|---|---|
| Where: | $P$ | = | axial load |
| | $\Theta$ | = | angle of braid weave |
| | $A$ | = | cross sectional area of a single wire |
| | $n$ | = | number of wires per strand |
| | $N$ | = | number of strands in assembly |
| | $s$ | = | fiber stress resulting from load |

Then: $$s = \frac{PANn}{\cos\Theta}$$

Care must be exercised in the use of this formula to take into account the braid attachment at the ends of the flex line. Although the tensile strength of the braid wire is quite high, the structure is only as strong as its weakest member which is, in the case of welded end attachments, the annealed heat affected zone adjacent to the weld nugget.

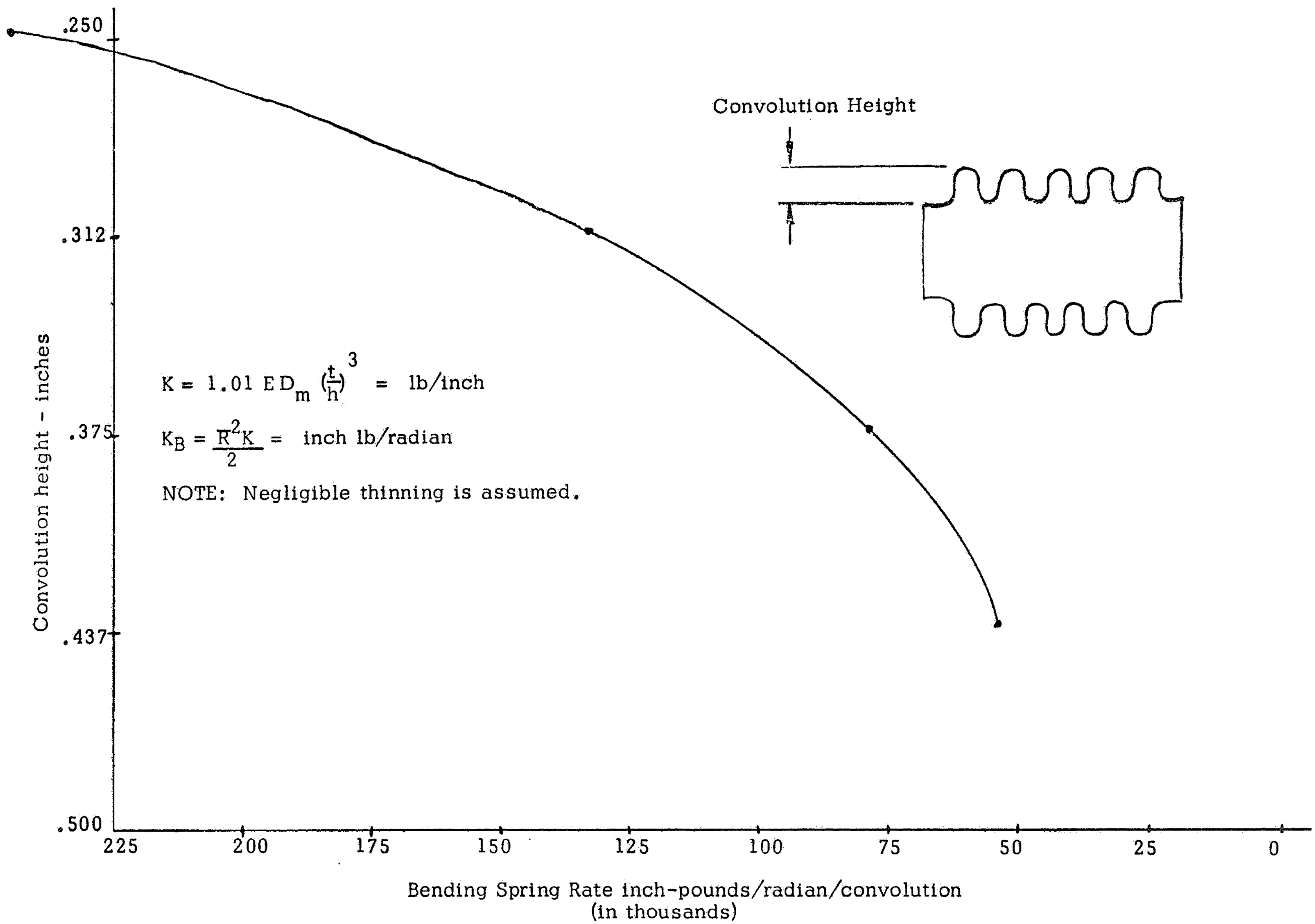
The flexibility of the braid does not so easily yield to analysis since major influences in this area are highly variable friction factors and the tendency of a tubular braid to "lock" in given position when end load is applied. If it weren't for these factors it might be practical to assume an analogy with a helical coil spring. However this not being the case, a preliminary evaluation test was conducted with a simple braided bellows assembly (single wall). The bellows assembly was a .010 inch, single ply CRES 316L, 10.00 inch diameter bellows with a tubular braid weave of $45^{o}$ with 96 strands, 17 wires per strand, .020 inch wire diameter, CRES 316L construction. The braided bellows assembly was pressurized to 0, 10, 20, 30, 40 and 50 psig and deflected to $180^{o}$ at each pressure. The temperature was $70^{o}$F and water was the pressurization media. The resistance to bending at various pressures is given in the Curve on Page 27. This total resistance includes all forces reacting against the load cell of course and it seems logical to assume that these forces are (a) bellows spring rate (very low), (b) hydraulic moment (indeterminant), (c) braid spring rate (very low) and (d) braid friction (indeterminant). It was observed during this test




($K_B$) Bending Spring Rate inch-pounds/radian/convolution

(in thousands)

Spring Rate Curve #4

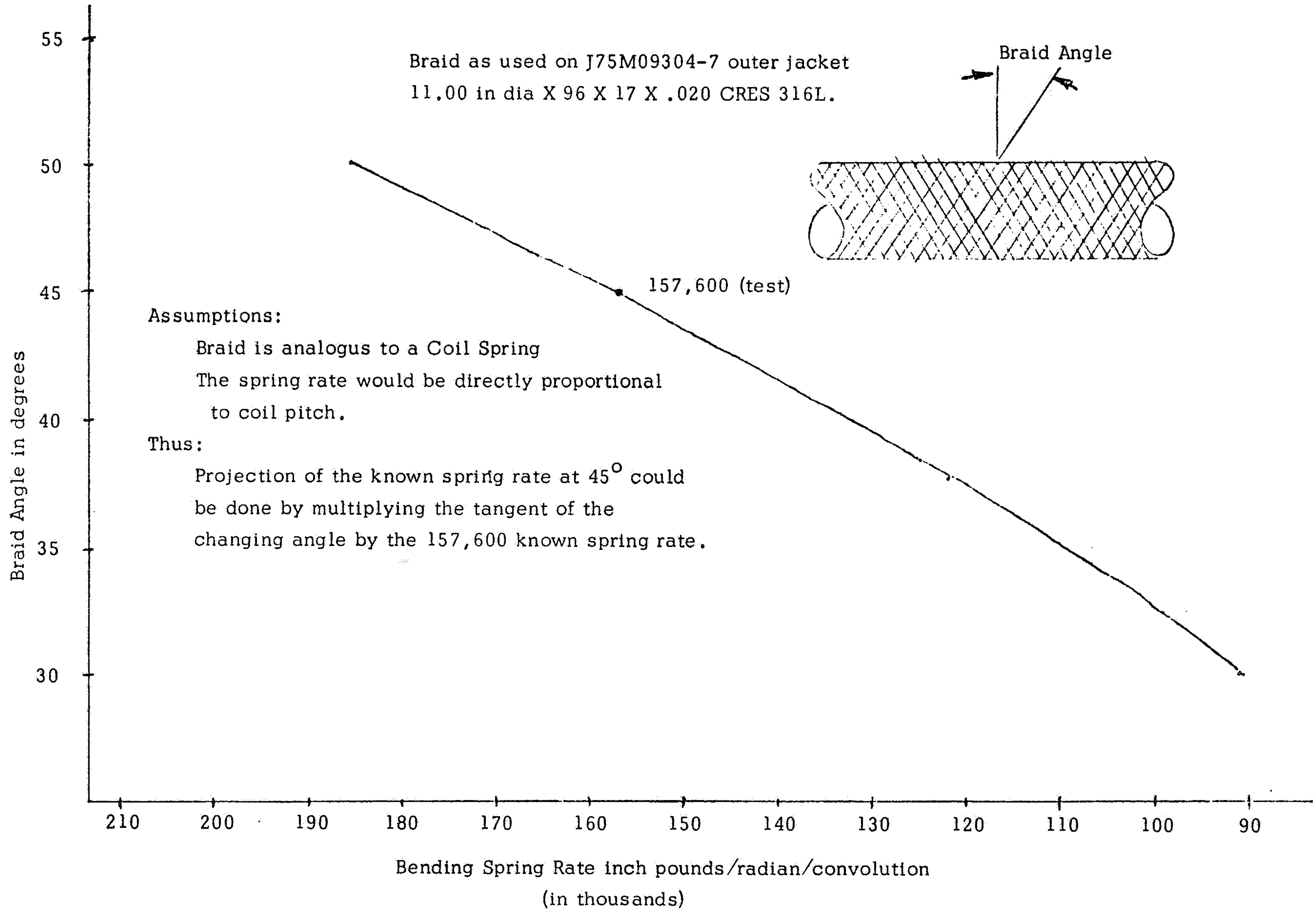



$K = 1.01\ ED_m \left(\frac{t}{h}\right)^3 =$ lb/inch

$K_B = \frac{R^2 K}{2} =$ inch lb/radian

NOTE: Negligible thinning is assumed.

Spring Rate Curve #5




Spring Rate Curve #6

that when the assembly was pressurized, bent to $180^{\circ}$ deflection and then released, it did not return to a straight position regardless of internal pressure up to 50 psig. It appeared from handling the assembly that this was caused by a tendency of the braid to lock the bellows in a deflected position of $30^{\circ}$ to $40^{\circ}$ under pressure. Some of this tendency must be attributed to simple yield and permanent set since when the assembly was unpressurized such a condition was also observed. However it was more difficult to return to the undeflected position with internal pressurization than without.

To determine the relative contribution of bellows and braid to the unpressurized spring rate of the same flex hose assembly as shown on Page 26, a test was conducted as outlined on Page 28. Thus it was established that each factor (bellows and braid) contribute nearly an equal amount of bending resistance when the assembly is not under pressure.

It was determined at this stage of evaluation that the scope of Phase I was complete for braid design and that further testing during Phase II was indicated before definite recommendations could be made. Based on damage evaluation, product evaluation and the test results just given it would seem logical to consider changing the braid angle or braid density.

3.1.3.3 Bellows Design

At the outset of the Phase I effort, in order to be objective, a survey of bellows analytical data was made and for reference the following bibliography is given:


A. J. A. Haringx - "Instability of Bellows Subjected to Internal Pressure", Philips Research Report 7, 189 - 196, 1952.

B. Zallea Expansion Joints, Catalog Number 56, 1956, Zallea Bros., Wilmington, Delaware.

C. C. M. Daniels - "Pressure Losses in Flexible Metal Tubing", Product Engineering, April 1956.

D. F. J. Feely, Jr. and W. M. Goryl - "Stress Studies on Piping Expansion Bellows", Journal of Applied Mechanics, Paper Number 44-APM-22.

E. M. W. Kellogg Company - Design of Piping System, Second Edition, 1956, John Wiley & Sons, New York, pp. 210 - 230.

F. W. Samans and L. Blumberg - "Endurance Testing of Expansion Joints", ASME Paper Number 54-103, 1954.

G. S. R. Kleppe - "High Pressure Expansion Joint Studies", ASME Paper Number 55-PET-10, 1955.

H. Turner and Ford - "Stress and Deflection Studies of Pipeline Expansion Bellows", Proceedings of the Institution of Mechanical Engineering, pp. 596-602, Volume 171, Number 15, 1957.

I. Dr. F. Salzman - "Ueber die Nachgiebigkeit von Wellrohrexpansionen", Schweizerische Bauseitung, Band 127, Number 11, 127 - 130, March 15, 1957.

J. "Simplified Formulas and Curves for Bellows Analysis", Atomics International Report NDA-SR-9848.

K. "State-of-theArt Survey of Metallic Bellows and Diaphragms for Aerospace Applications", AFRPL-TR-65-215.

L. "Bellows Spring Rate for Seven Typical Convolution Shapes", by James D. Matheny; Published in Machine Design, January 4, 1964.

For the design of a bellows as used in a braided flex hose there are three major considerations which must be dealt with (a) bellows spring rate, (b) bellows hoop stress and (c) bellows deflection stress. The following formulas and their derivations are taken from the preceding sources. The empirical factors are as explained and are based on experience.

Nomenclature

| | | |
|---|---|---|
| O.D. | = | Outside diameter (inches) |
| I.D. | = | Inside diameter (inches) |
| $D_m$ | = | Mean diameter (inches) |
| $L_c$ | = | Convolution length (inches) |
| h | = | Height of convolution (inches)* |
| t | = | Thickness of single ply (inches) |
| N | = | Number of ply |
| n | = | Number of active convolutions |
| E | = | Modulus of elasticity (psi) |
| P | = | Bellows axial load (pounds) |
| $\delta_1$ | = | Deflection of quarter convolution |
| $\delta$ | = | Total bellows axial deflection (inches) |
| I | = | Moment of inertia (in.$^4$) |
| $\bar{R}$ | = | Mean Radius |
| K | = | Bellows axial spring rate $(\frac{lb.}{in.})$ |
| $\eta$ | = | Thinning factor |
| $\sigma$ | = | Stress |
| M | = | Moment (in-lbs) |
| C | = | Distance from neutral to outer fiber of beam (inches) |
| $\theta$ | = | Angular deflection of bellows (degrees) |
| $\delta_e$ | = | Equivalent axial deflection (inches) |
| $t_e$ | = | Effective bellows wall thickness |

*See Figure 3 on Page 31

(a) <u>AXIAL SPRING RATE:</u>

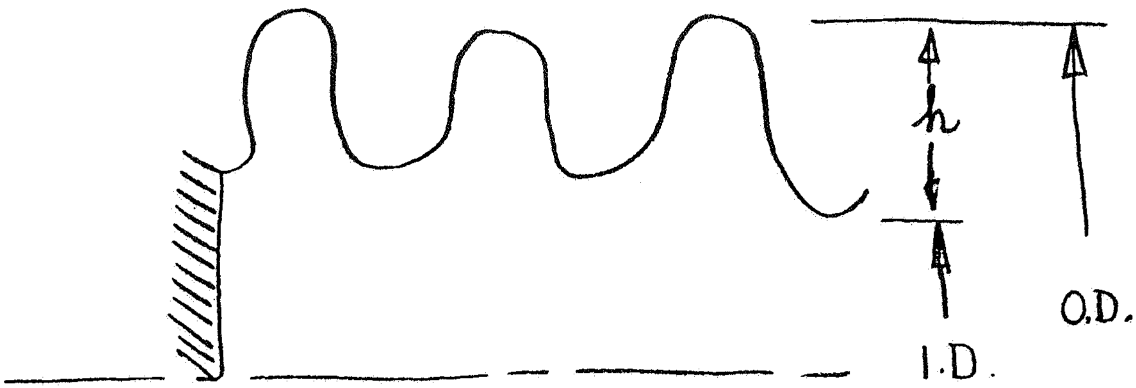



FIGURE 1

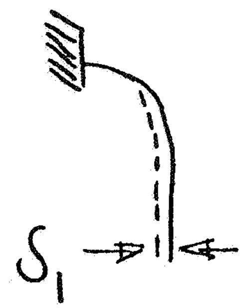


FIGURE 2

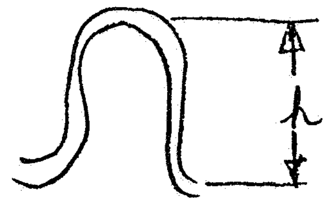



FIGURE 3

As shown in Figure 2, deflection of 1/4 convolution is,

$$\delta_1 = \frac{P\left(\frac{h}{2}\right)^3}{3\ EI} = \frac{Ph^3}{24\ EI} \qquad \text{Ref I, L} \qquad (1)$$

$$I = \frac{D_m \pi\ t^3}{12} \qquad (2)$$

Substituting equation (2) in (1),

$$\delta_1 = \frac{Ph^3}{24E}\ \frac{12}{D_m \pi\ t^3} = \frac{P}{2\pi\ E\ D_m}\left(\frac{h}{t}\right)^3$$

<u>Spring rate</u>,

$$K_1 = \frac{P}{\delta_1} = P\ \frac{2\pi\ E\ D_m}{P}\ \left(\frac{t}{h}\right)^3 = 2\pi\ E\ D_m\ \left(\frac{t}{h}\right)^3 \qquad (4)$$

For one convolution the total spring rate is,

$$\frac{1}{K} = \frac{1}{K_1} + \frac{1}{K_1} + \frac{1}{K_1} + \frac{1}{K_1}$$

$$K = \frac{1}{4}(K_1) = \frac{1}{4}(2\pi E D_m \left(\frac{t}{h}\right)^3$$

$$K = \frac{\pi E D_m}{2} \left(\frac{t}{h}\right)^3 \qquad (5)$$

For $n$ convolutions and $N$ plies, the total spring rate is, $(K_t)$

$$\frac{1}{K_t} = \sum_{n=1}^{n} N \left(\frac{1}{K}\right) \qquad \text{or,}$$

$$K_t = \frac{N}{n} K = \frac{\pi}{2} E D_m \left(\frac{t}{h}\right)^3 \frac{N}{n}$$

$$K_t = 1.57 \; E D_m \left(\frac{t}{h}\right)^3 \frac{N}{n} \qquad (6)$$

However, the calculated spring rate from equation (6) is different from the measured actual spring rate thus an empirical equation which is similar to equation (6) was obtained as,

$$\boxed{K_t = 1.01 \, E D_m \left(\frac{\eta t}{h}\right)^3 \frac{N}{n} \quad .} \qquad (7)$$

Where $\eta$ is a dimensionless thinning factor, the values of the thinning factor were tabulated as,

| | | |
|---|---|---|
| $\frac{O.D.}{I.D.}$ = 1.2 - 1.3 | 1.35 - 1.4 | 1.4 - 1.50 |
| $\eta$ = 1 | 0.9 | 0.85 |

Translating this from axial to bending spring rate,

$$K_B = \frac{\bar{R}^2 K}{2} = \text{inch lbs/radian}$$

(b) DEFLECTION STRESS:

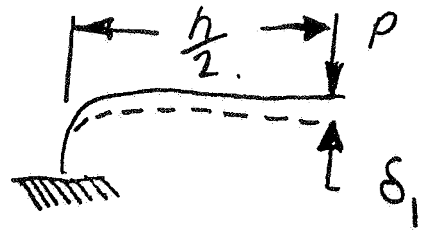



FIGURE 4

Deflection for 1/4 Convolution,

$$\delta_1 = \frac{\delta}{4n} \tag{8}$$

Stress $\sigma = \frac{Mc}{I}$

$$c = \frac{t}{2}$$

$$I = \frac{D_m \pi t^3}{12}$$

$$M = P \left(\frac{h}{2}\right)$$

from equation (1), $\delta_1 = \dfrac{P \left(\frac{h}{2}\right)^3}{3\ EI}$

Substituting equation (1) in equation (8),

$$\delta = 4n \ \delta_1 = \frac{n \ Ph^3}{6 \ EI}$$

$$P = \frac{6 \ EI\delta}{n \ h^3} \tag{9}$$

Substituting M, c, I, in stress equation obtaining,

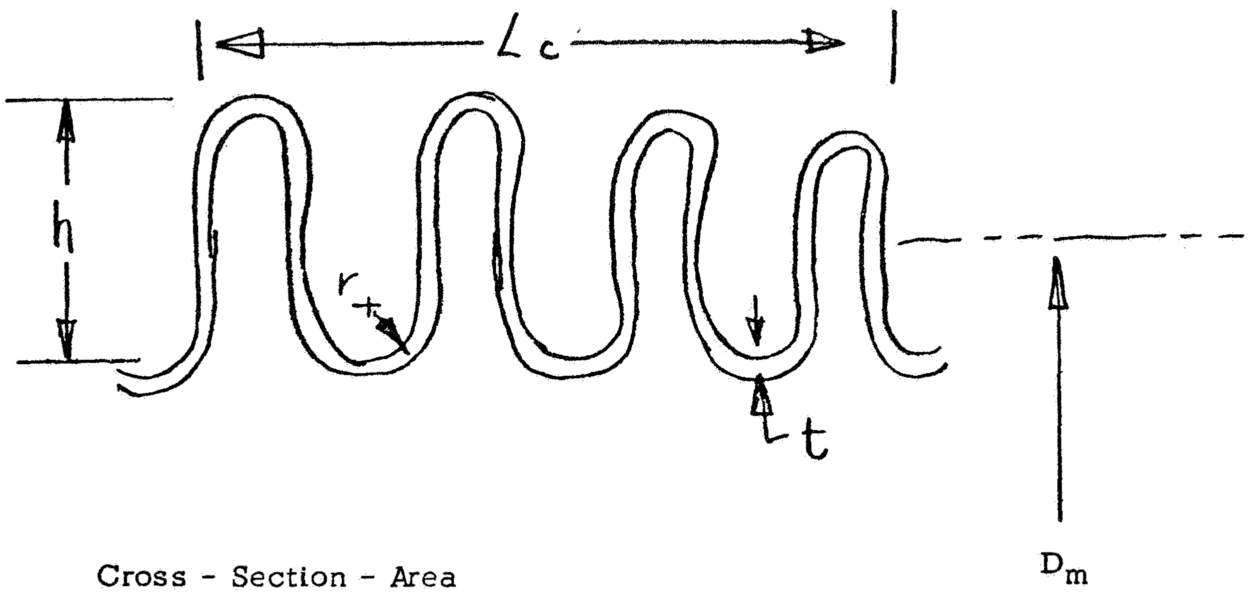
$$\sigma = \frac{6E\delta}{n \ h^3} \left(\frac{h}{2}\right) \left(\frac{t}{2}\right)$$

$$\sigma = 1.50 \ \frac{Et\delta}{n \ h^2} \tag{10}$$

This resulting equation is modified by empirical data with 1.38 replacing 1.50 as follows:

$$\sigma = \frac{1.38 \ E t \delta}{n \ h^2} \qquad (11)$$

Bellows Hoop Stress Formula Derivation




Cross - Section - Area

$$A = 2 \left[ 2\pi r t n + 2 n t \ (h - 2r) \right]$$

Hoop stress $\quad \sigma_H = \frac{F}{A} = \frac{p \ D_m \ L_c}{A}$

$$\sigma_H = \frac{p \ 2 \bar{R} \ L_c}{2 \ [2\pi rtn + 2 \ nt \ (h-2r)]} = \frac{p \ \bar{R} \ L_c}{2\pi rtn + 2 \ nt \ (h - 2r)}$$

Letting $t_e = \frac{2\pi rtn + 2nt \ (h - 2r)}{L_c}$ EFFECTIVE THICKNESS

$$= rt \ (\pi - 2) + ht \ (\frac{2n}{L_c})$$

For evenly spaced convolutions

$$r = \frac{L_c}{4n}$$

$$\therefore t_e = \frac{L_c t}{4n} \ (\pi - 2 + \frac{4nh}{L_c}) \quad \frac{2n}{L_c}$$

$$= \frac{t}{2} \ (1.142 + \frac{4nh}{L_c})$$

$$\sigma_H = \frac{P\bar{R}}{t_e}$$

In order to illustrate the application of the foregoing formulas to the actual bellows designs in use at Launch Complex 39 the following design curves are given. The curves are based on the equation for solving the bellows spring rate in bending.

Functionally the inner line flex hose bellows must be designed as a highly flexible pressure carrier capable of many cycles of deflection. The outer bellows must be capable of the same flexure and cycle life but only at one atmosphere of external pressure. However it is desirable to make the outer bellows highly resistant to external damage since it has been found in Paragraph 3.1.1 "Hardware Evaluation" that this type of damage is the most common failure mode in service for the assembly as a whole. One way of making the outer jacket bellows more resistant to dents without increasing the bending spring rate significantly would be to construct it of more than one ply material. An .016 inch total thickness could be attained with two ply of .008 inch thick material while actually decreasing the spring rate as follows:

<u>Present design of 8-060107-7</u> (used as outer jacket on 75M09304-7 Arm #7)

| | | |
|---|---|---|
| I.D. | = | 10.00 |
| O.D. | = | 10.75 |
| h | = | .375 |
| n | = | 3 convolutions/inch |
| t | = | .010 |
| $\underline{N}$ | = | 1 ply |
| $\bar{R}$ | = | 5.188 |
| E(Young's Modulus) | = | $29 \times 10^6$ |

<u>Spring Rate as presently designed:</u> lbs/inch (per convolution)

$$K = 1.01\ EDm \left(\frac{t}{h}\right)^3 (N)$$

$$K = 1.01\ (29 \times 10^6)\ (10.375) \left(\frac{.010}{.375}\right)^3 (1) =$$

5705 lb/inch/convolution (axial spring rate)

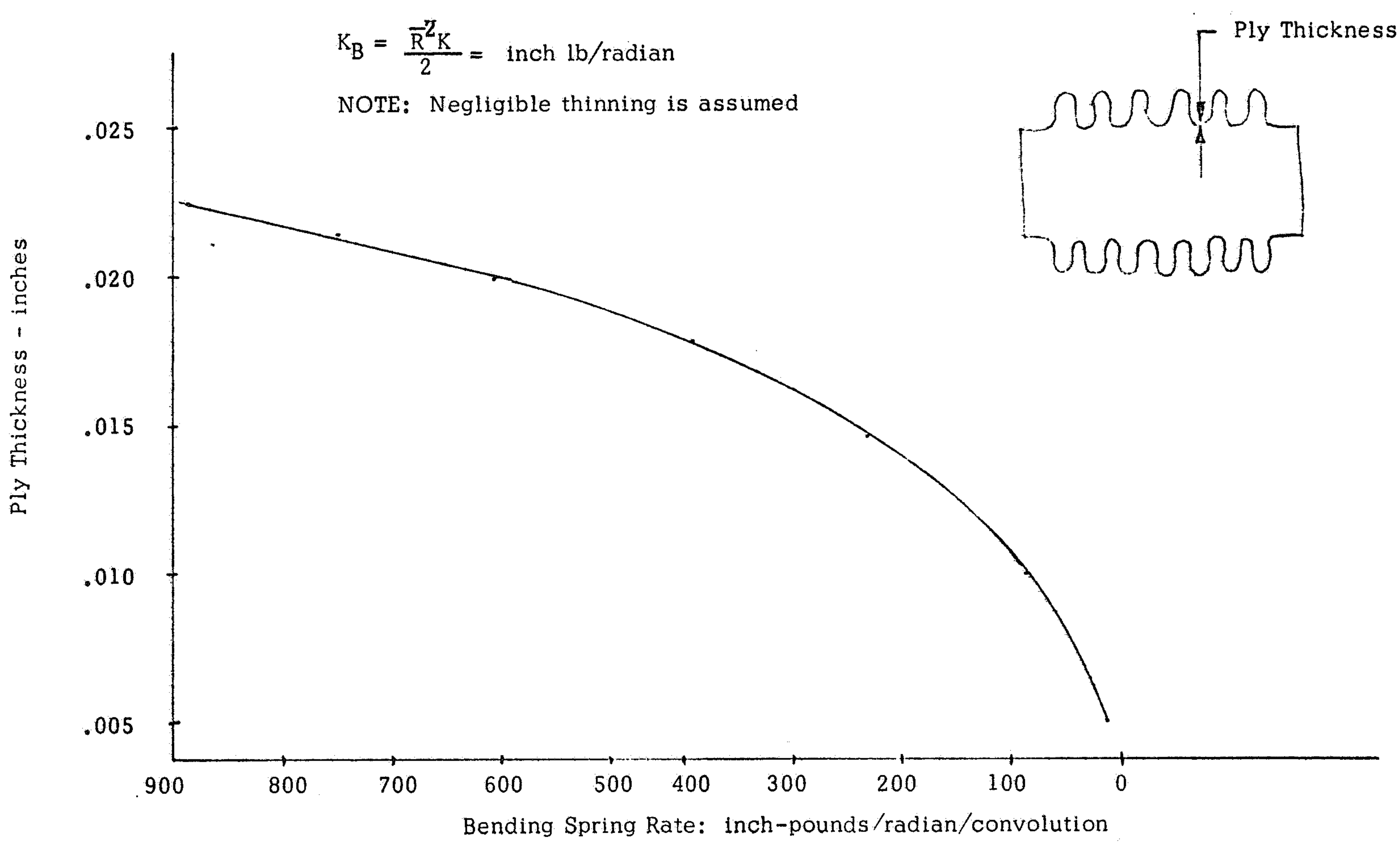
$$K_B = \frac{\bar{R}^2 K}{2} = \frac{(5.188^2)\ (5705)}{2} =$$

76,785 inch-lb/radian convolution (bending spring rate)

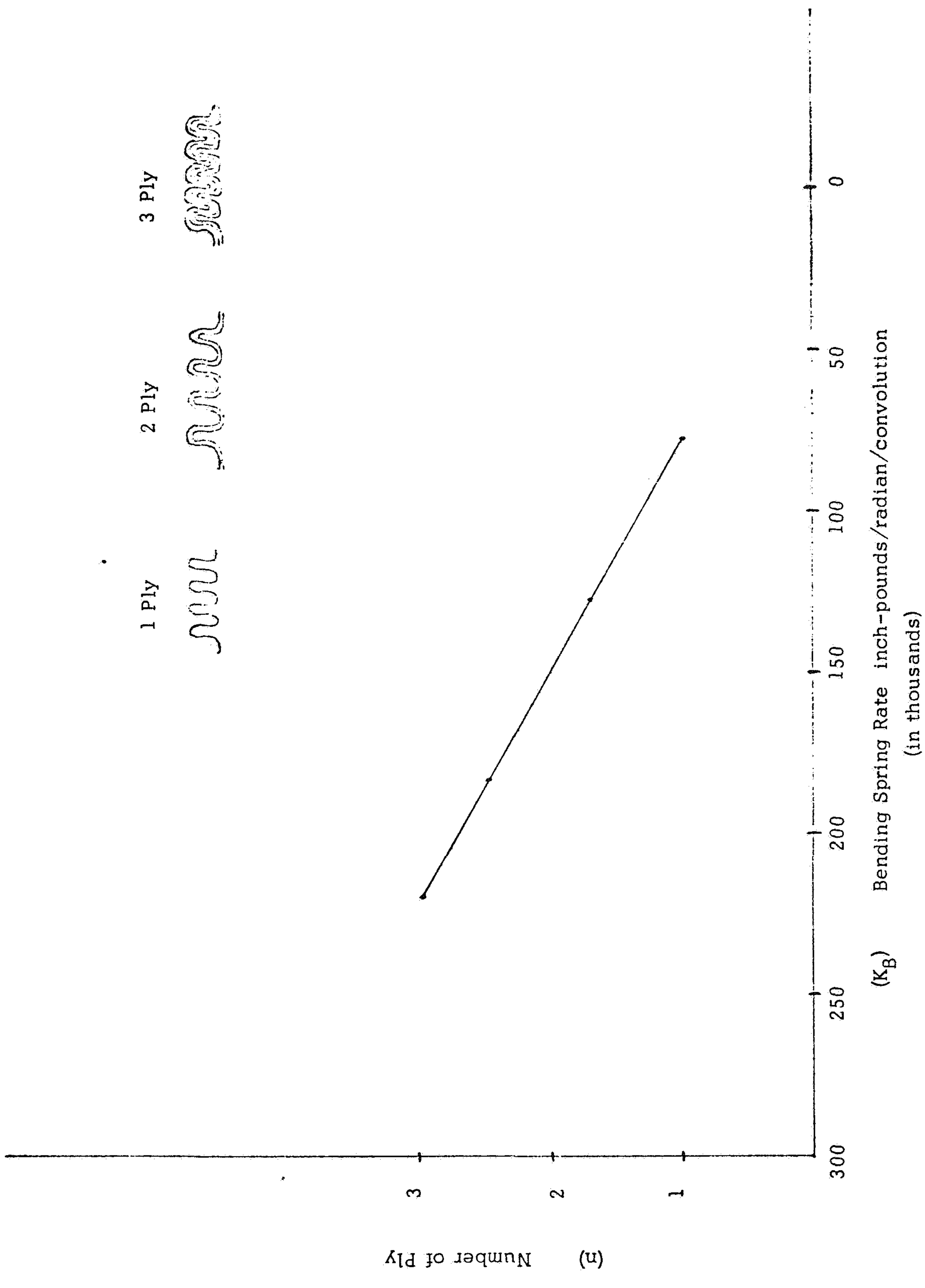
$K = 1.01\, E D_m \left(\frac{t}{h}\right)^3 \frac{N}{n} =$ lb/inch

$K_B = \frac{\bar{R}^2 K}{2} =$ inch lb/radian

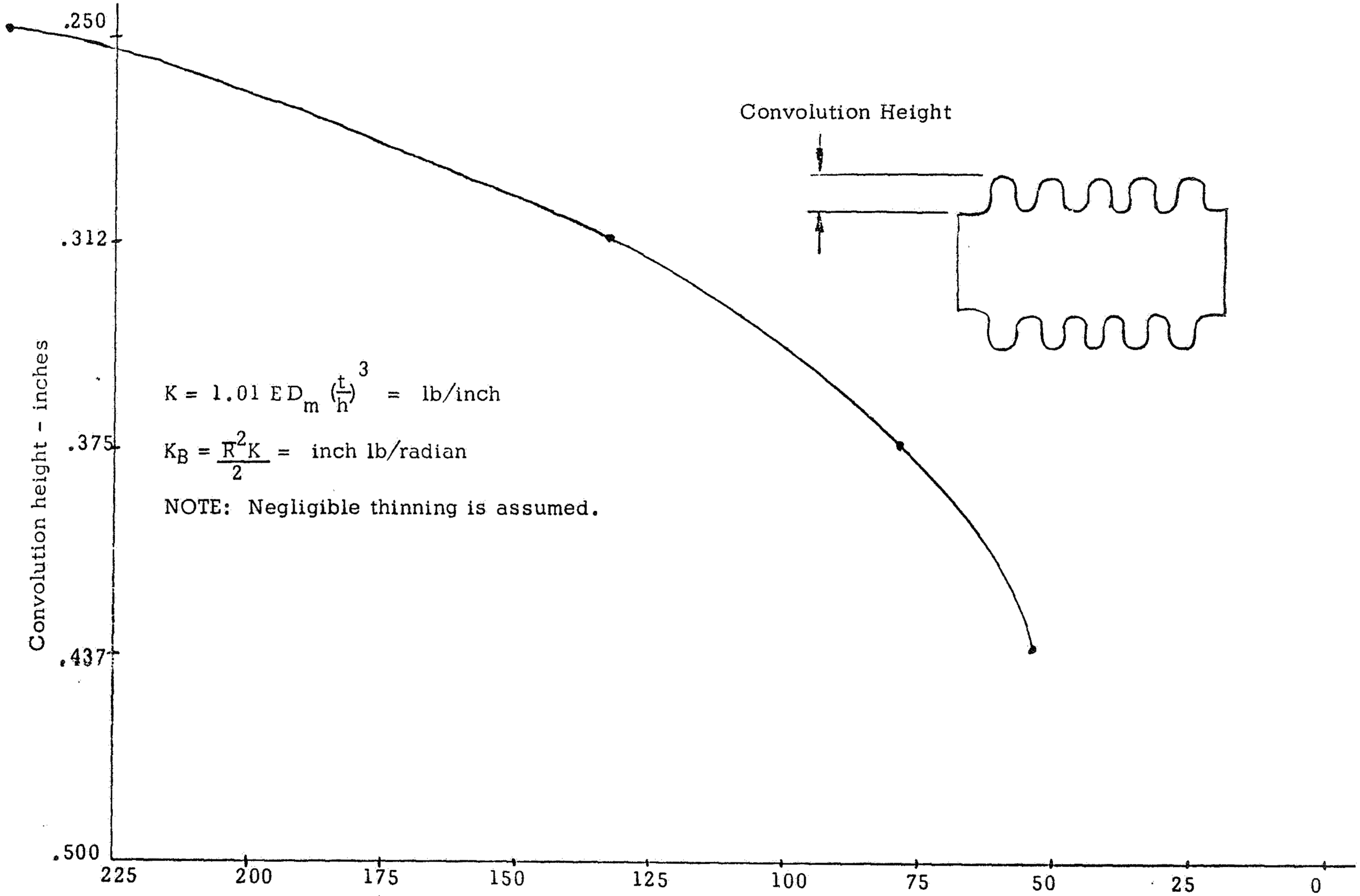
NOTE: Negligible thinning is assumed




Spring Rate Curve #8




Spring Rate Curve #9




Bending Spring Rate inch-pounds/radian/convolution
(in thousands)

Spring Rate Curve #10

Spring Rate if changed to 2 ply of .008: (per convolution)

$$K = 29 \times 10^6) (10.375) \left(\frac{.008}{.375}\right)^3 (2)$$

5,842 lb/inch/convolution (axial spring rate)

$$K_B = \frac{\overline{R}^2 K}{2} \quad \frac{(5.191^2)(5842)}{2}$$

$$= 78{,}700 \text{ inch-lb/radian convolution (bending spring rate)}$$

Spring rate if changed to one ply of .020 with .750 high convolution

$$K = (29 \times 10^6) \; (10.75) \; \left(\frac{.020}{.750}\right)^3 (1) =$$

5,900 lb/inch/convolution (axial spring rate)

$$K_B = \frac{\overline{R}^2 K}{2} = \frac{(5.388^2)(5900)}{2} =$$

$$= 85{,}600 \text{ inch/lb/radian convolution (bending spring rate)}$$

As is also demonstrated in the foregoing, an increase in the convolution height could accomplish the same general result while doubling the total material thickness of the bellows to .020 inch but maintaining a single ply construction. The advantages of the multiple ply construction would be (a) greater cycle life since by inspection of equation Number 11, from page 34,

$$\sigma = \frac{1.38 \, E t \delta}{n \, h^2}$$

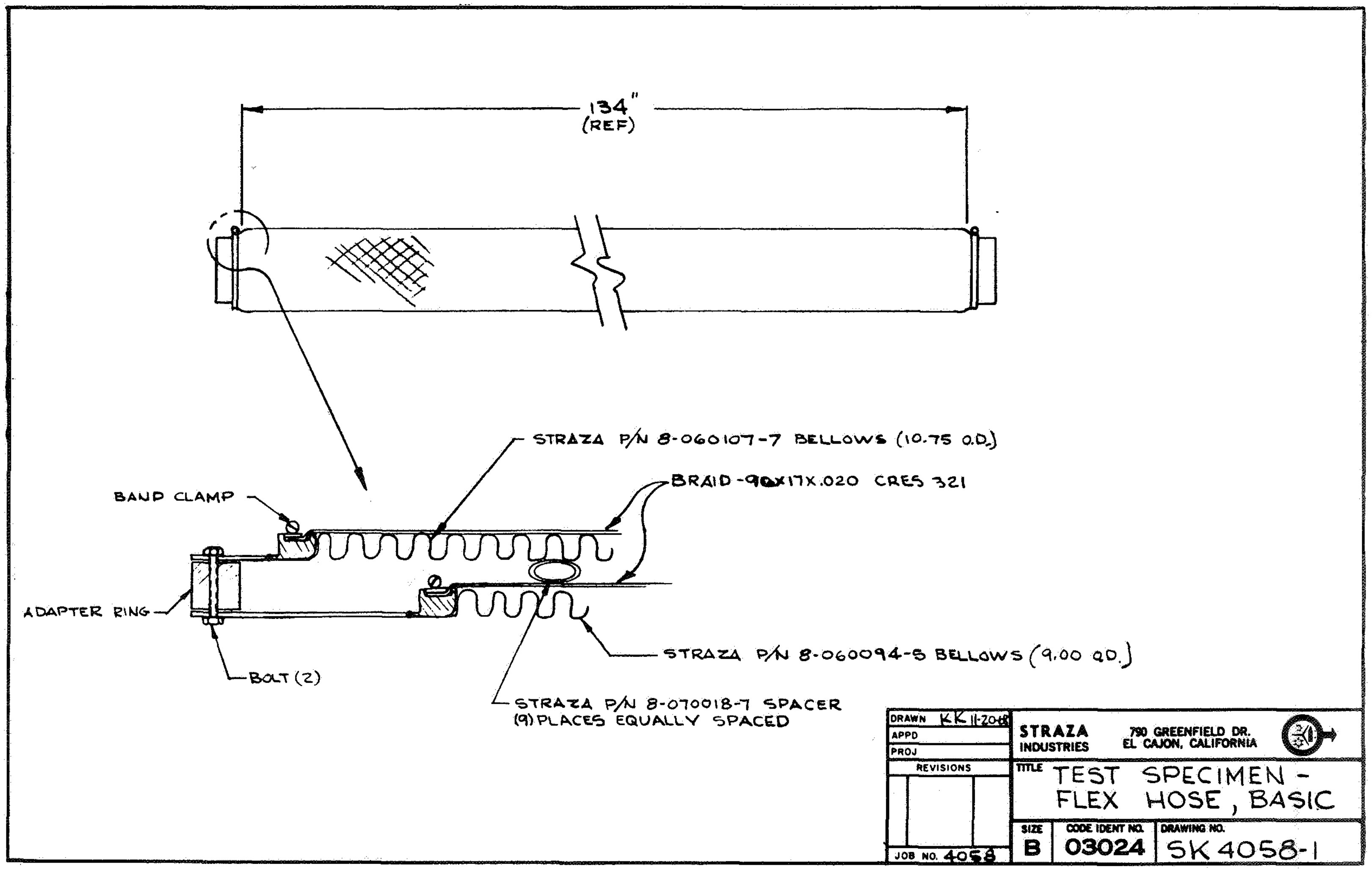
When material thickness "t" is reduced, then the stress must be smaller; and (b) increased total wall thickness for resistance to impact loads. However there are major disadvantages. The added cost cannot be ignored since great care in the fabrication of multiple ply bellows must be given to insuring against contamination between plies. Such contamination can cause stress concentrations and built-in corrosion sources. In addition, since many failures of bellows were observed to have involved abrasion, the thinner outer ply would tear more quickly and a single ply failure would result in loss of bellows integrity necessitating repair the same as if both plies were punctured. The only disadvantage of increasing the convolution height to attain a more rugged bellows would be an increase in assembly diameter or decrease in annular space between jacket and inner line. However in both cases the weight would obviously be greater and it is questionable whether a significant amount of ruggedness improvement would result. Any thin material exposed directly to impact and abrasion is of questionable endurance.

3.1.3.4 General Design

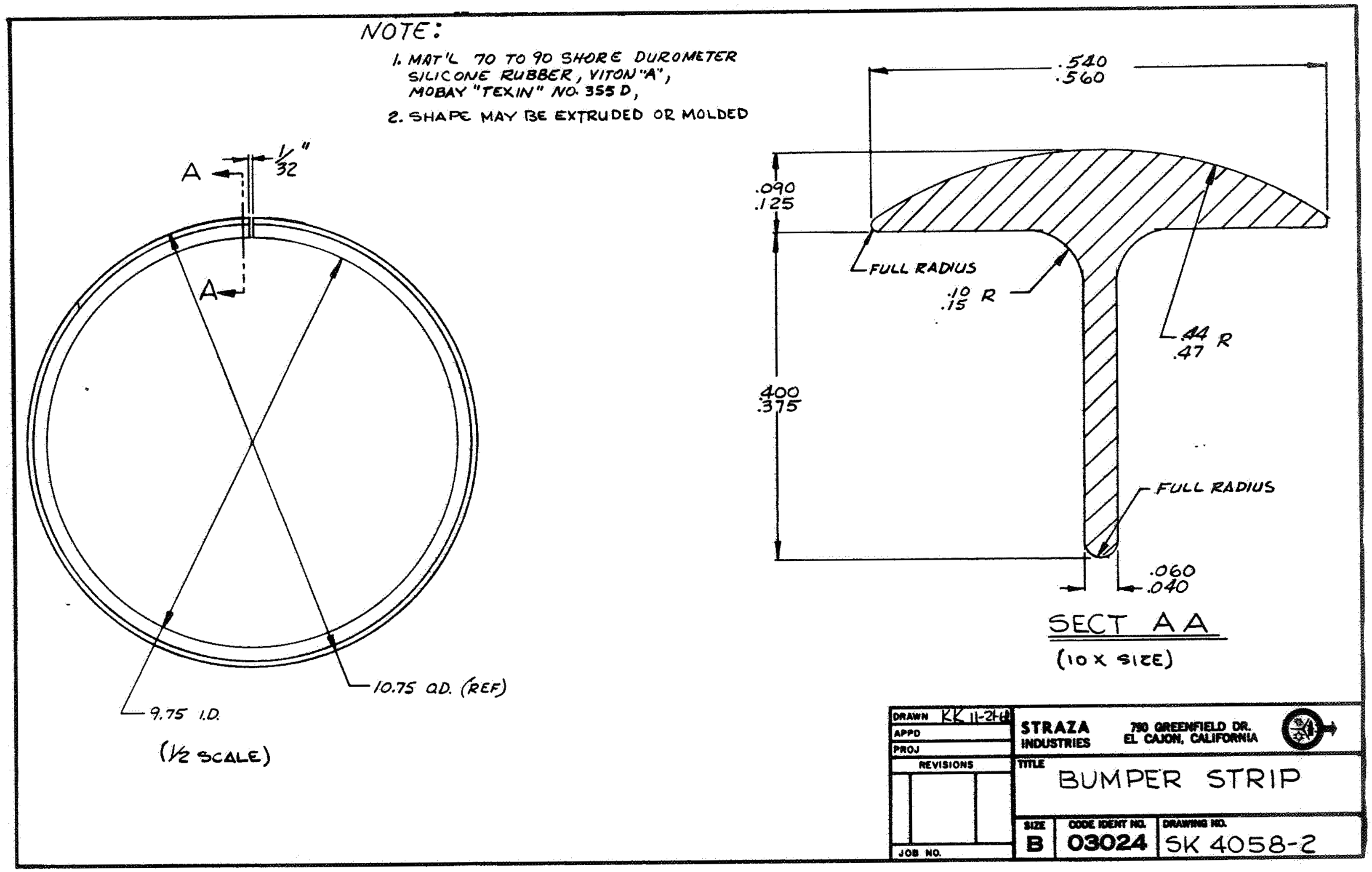
One means of increasing outer jacket ruggedness for the flex lines would be placement of energy absorbent material around the bellows. Several candidate materials and configurations were evaluated preliminarily in the "Product Review", Paragraph 3.1.2. Since the application of a molded tip or wrap-around bumper to bellows convolutions would not affect resistance to bending and would not decrease flexure cycle life it appears a promising solution to the problem. Any such material must be tough, abrasion resistant, resilient and thermal shock resistant. Several candidate materials are suggested: Teflon, Nylon, silicone rubber and Viton A. Adhesion to steel and moldability must also be considered and with this in mind, probably silicone rubber would be the best all-around material. However, all four must be given consideration.

The scope of this study includes investigation of means to improve maintainability of flex lines. After review of the kinds of maintenance and refurbishment which are necessary as given in "Hardware Evaluation", Paragraph 3.1.1, it was concluded that the most critical need is to plan the design and construction of lines such that they may be easily disassembled and re-assembled. Wherever possible in the construction of a V. J. flex line, consideration should be given to ease of removal of major components with modular design concepts.

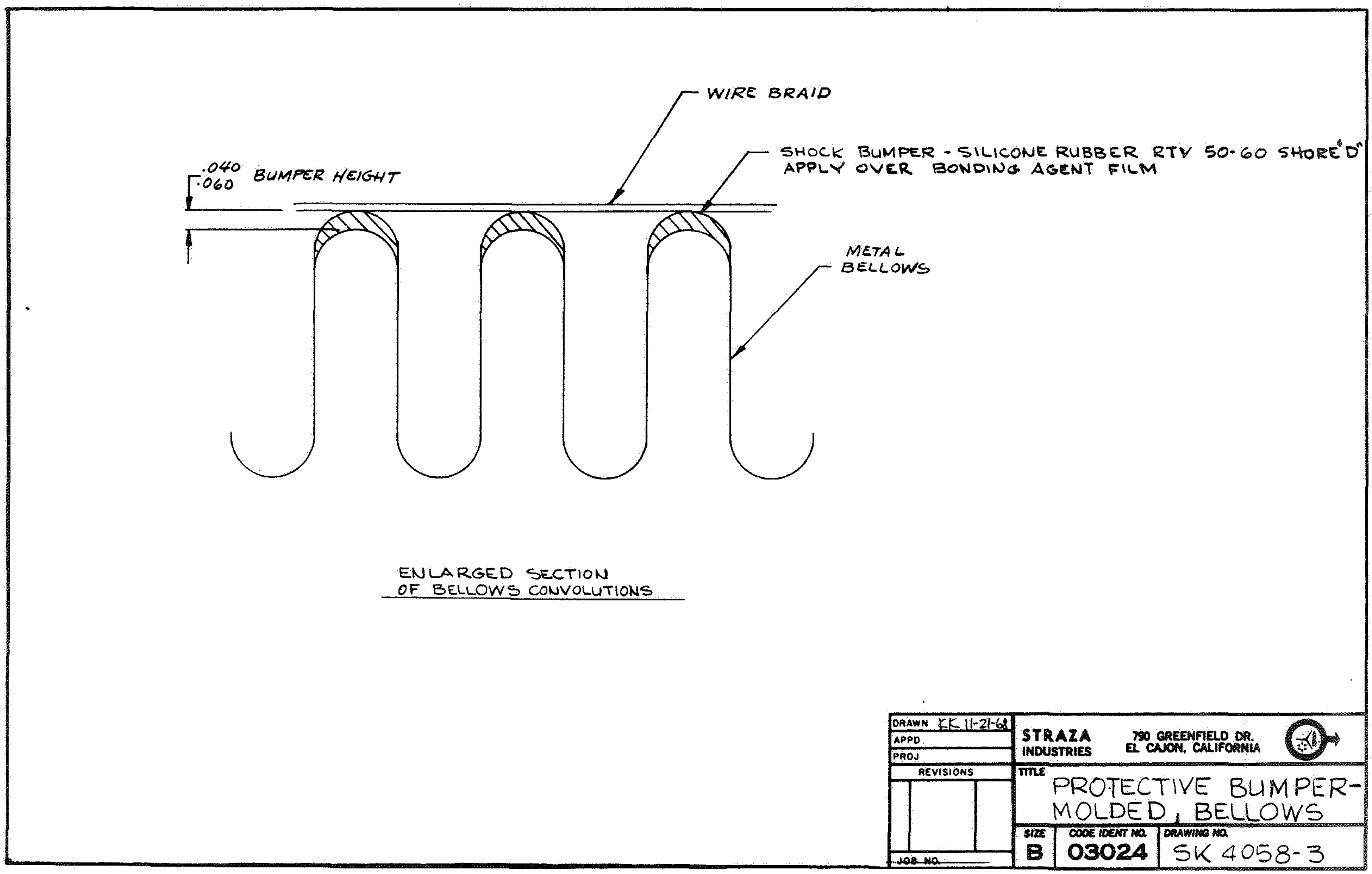
One proposed design innovation is clamp attachment of outer jacket braid. Since this braid carries no end loading due to pressure and is a protective cover, it could have a band clamp at each end of the line to hold it in place. When damage to outer jacket bellows is to be repaired the clamp could easily be removed and replaced and in this way grinding out of a weld and subsequent re-welding could be avoided. In many instances this could mean the difference between field repairable damage and that which must be done in a shop. A typical design example is given in Figure SK4058-6.



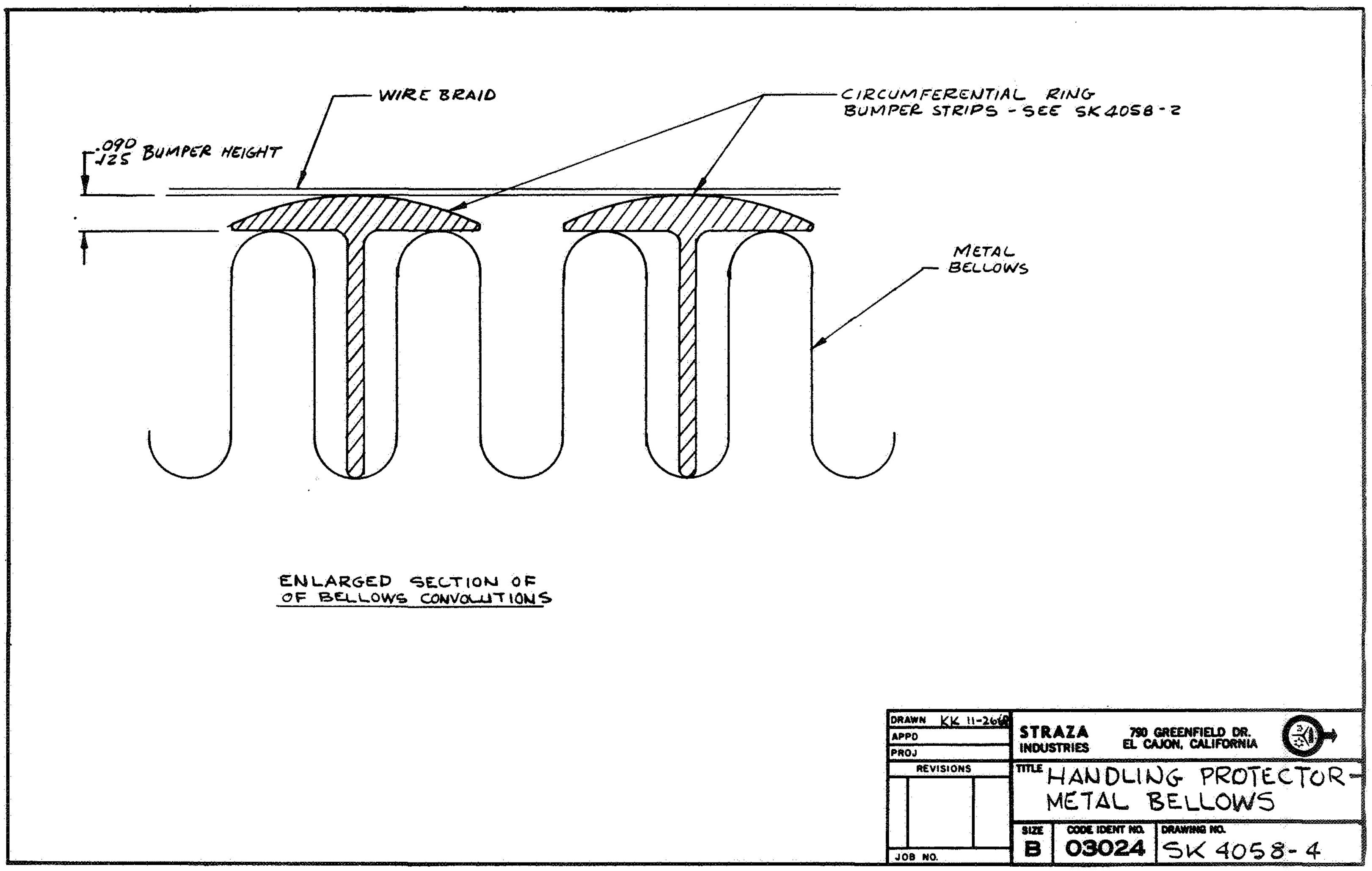

AMETEK/Straza Drawing SK4058-1 Test Specimen



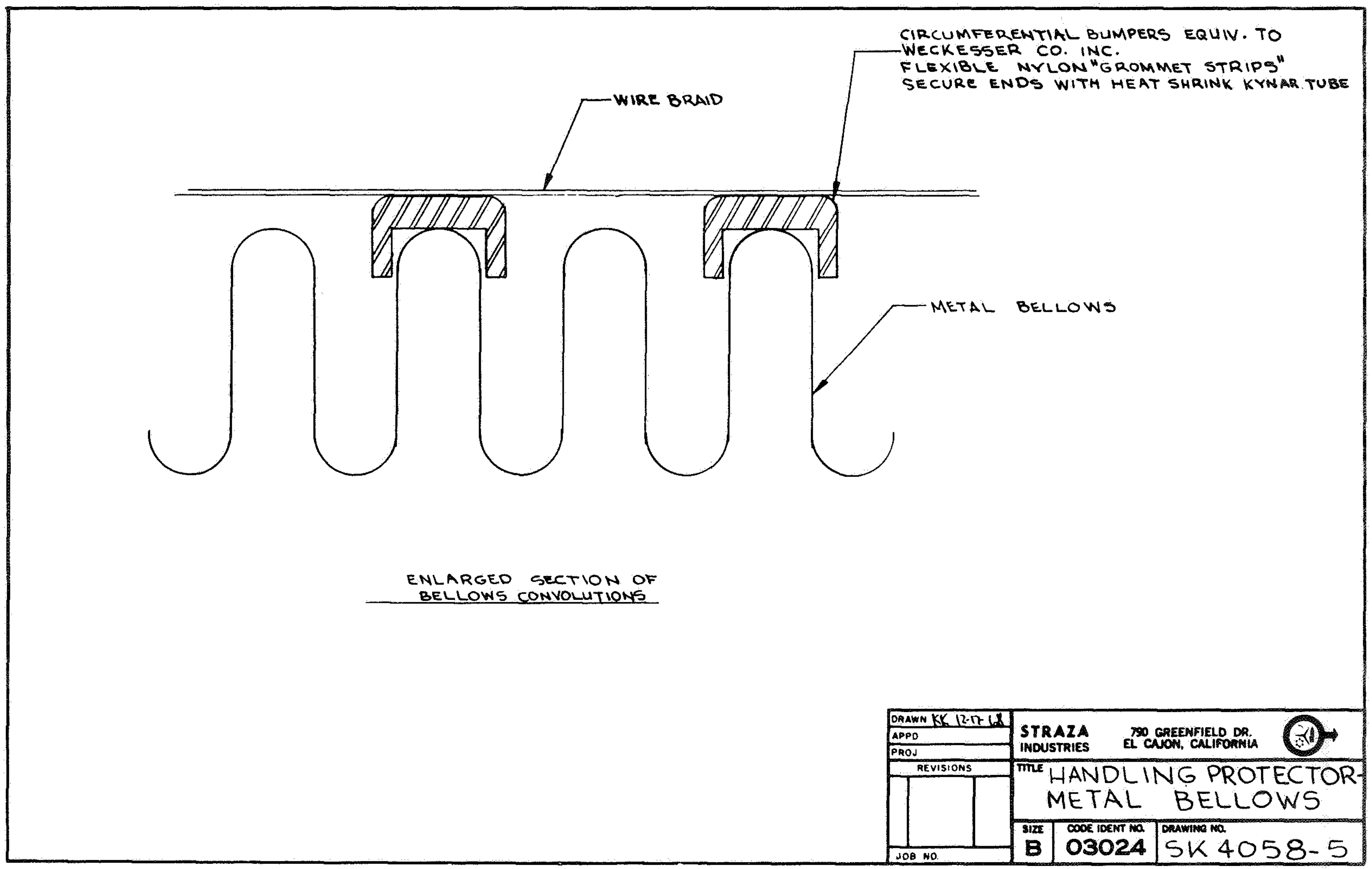

AMETEK/Straza Drawing SK4058-2 Bumper Strip



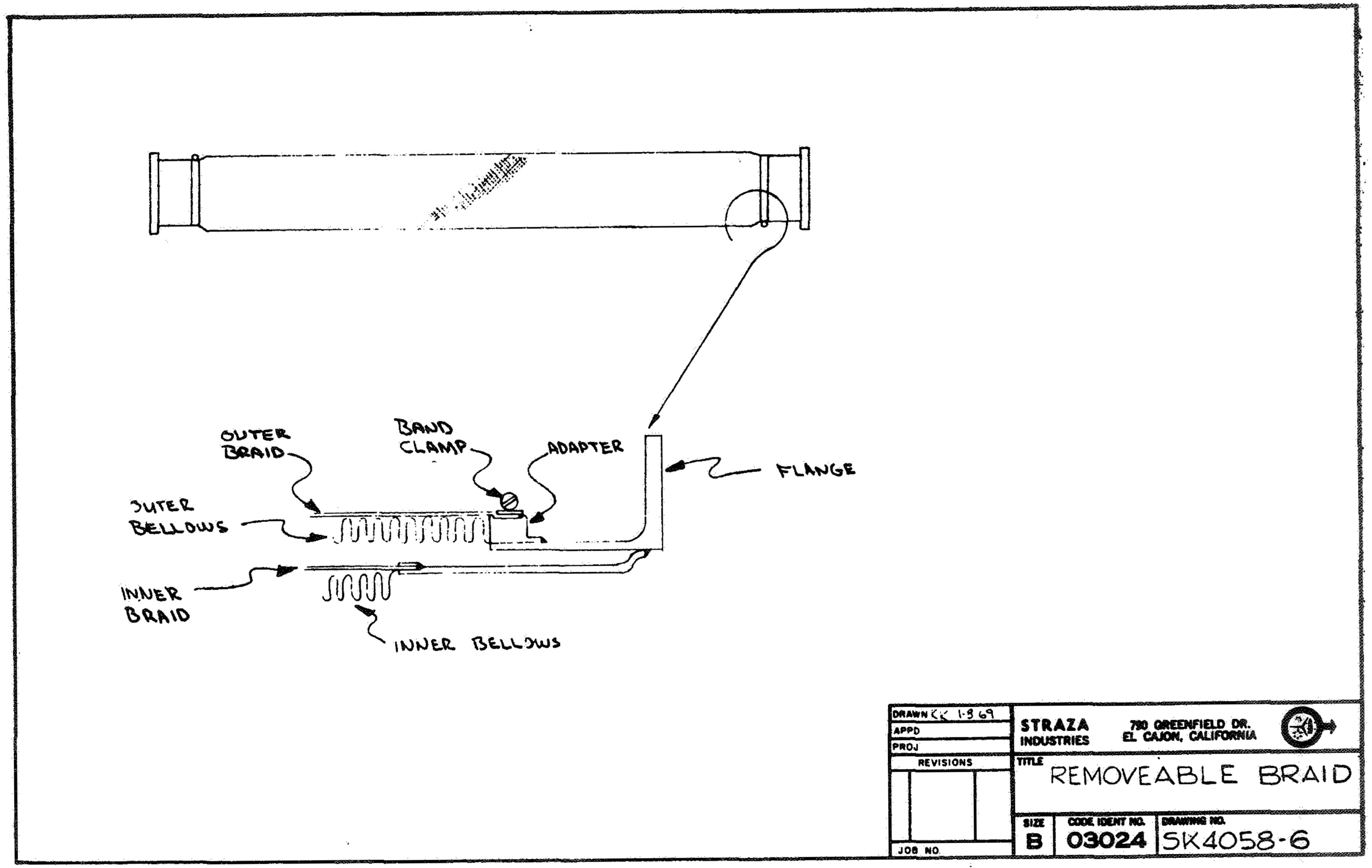

AMETEK/Straza Drawing SK4058-3 Protective Bumper




AMETEK/Straza Drawing SK4058-4 Handling Protector




AMETEK/Straza Drawing SK4058-5 Handling Protector




AMETEK/Straza Drawing SK4058-6 Removable Braid

### 3.1.4 Test Plan

#### 3.1.4.1 Scope

This document sets forth the plan for verification testing of vacuum jacketed flex hose design improvements resulting from the Phase I study portion of Task 3, Sub-task 1 of NASA Purchase Order NAS 10-6098. These tests will serve as the evaluation factors in selecting valid design improvements for recommendation.

A flex line test specimen similar to those in use on the Saturn V launch umbilical tower will be used for a set of baseline tests to establish the flexural resistance, ruggedness and high and low temperature effects. After baseline values are established in this manner, each design improvement proposed will be tested. Tests in all cases will be uniform; only the specimens will change.

Since it is the purpose of this program to generate specific solutions to design problems initially evaluated in Phase I, those tests which do not support this goal are not proposed. Those tests which might be valuable depending on other test results are conditionally proposed. A complete documentation program consistent with the scope of work and project goals is proposed as an integral part of this test plan.

#### 3.1.4.2 Testing Philosophy

The Phase I portion of the program generated some definite design improvement configurations which should help eliminate the major cause of line failure in service (external handling damage). These proposed improvements can best be evaluated by a testing program which duplicates the conditions of failure which are to be overcome. The ruggedness testing herein described makes use of a test fixture which duplicates the types of damage due to external shock and abrasion loading which have been documented for line failures in the Phase I Hardware Evaluation. Since the design improvements aimed at improved ruggedness are external shock absorbers they will in addition to ruggedness testing, be exposed to storage and launch conditions of flexure, temperature and atmospheric exposure.

In addition to the specific design improvements which were developed in Phase I, the problem of increased flexibility was explored and to some extent analyzed. The results have been some definite design change suggestions such as braid angle increase in outer jacket bellows and greater convolution height in both inner and outer bellows. (See Phase I Report for Analysis.) These design improvements can be reliably analyzed as shown in the Phase I report and testing in this area is not proposed. However, the line flexure and induced structure loading when the flex lines are pressurized is an area which the Phase I analysis and preliminary tests have identified as a problem which requires further testing before definite design changes can be suggested. It is therefore a part of this test plan to evaluate the relative flexibility of the lines with and without internal pressure.

It is then the philosophy of this test plan to (a) design proof test the proposed improvements and (b) run analytical tests to determine extent of line flexure problem and possible solutions to it.

3.1.4.3 Test Specimens

The basic design of the test specimens for design proof flexure, ruggedness, vibration and cycling will be per NASA J75M09304-13. (AMETEK/Straza P/N 8-030140-3.) This is a typical example of present state-of-art design and construction of a jacketed flex line as used on the Launch Umbilical Tower for the Saturn V Program. Its history of damage is typical of other lines on the swing arms. This basic design and construction will be modified for testing purposes as shown on the accompanying SK4058-1 drawing. These modifications are made to allow flexure tests to be run on the same assembly in various stages of build-up of the line, to allow quick inspection of line interiors and to eliminate costly flanges and valves which are not pertinent to the tests. The basic specimen as shown on SK4058-1 will be used for baseline tests in all cases and will be used for non-pressurized flexure tests. The basic specimen will be modified by adding the design improvements as shown on drawings SK4058-3, -4 and -5 for the design improvement evaluation tests. Two (2) complete specimens will be fabricated.

The proposed testing can be accomplished by successive modification and repair of these two units. The flexural evaluation, salt spray and thermal tests will require special configurations as described in the applicable test descriptions herein.

3.1.4.4 Testing Requirements

3.1.4.5 Testing

Tests have been established to thoroughly evaluate structural capability and environmental integrity of the proposed flexible line assemblies. The tests to be accomplished are:

A. Flexural Resistance Testing - Design Proof

B. Flexural Resistance Testing - Evaluation

C. Ruggedness Testing

D. Thermal Tests - Low and High Temperature

E. Salt Spray Testing

F. Vibration Testing

Flexural Resistance Testing - Design Proof

Test set-up will be as shown on Page 57 with specimen laid flat on rolling platforms while restrained at the center. The force required to move the specimen from the straight position through an angle of $180^{o}$ for a "U" shaped position will be measured by a 0 - 1,000 pound force gage. Inner line will be at ambient temperature and pressure. Line will be bent from straight "A" position to "B" bent position, force recorded, allowed to return to straight position, bent in opposite direction to reverse "B" position, force recorded, allowed to return to straight position, rotated about its longitudinal axis $90^{o}$ and the foregoing flexure procedure repeated. The average of the recorded forces shall then be recorded in the space provided on the data sheet. This flexure test will be run as follows:

A. On inner line bellows only.

B. On inner line bellows with braid.

C. On inner line bellows with braid and radiation shielding.

D. On complete assembly with outer jacket bellows, braid and spacers, per SK4058-1.

E. On complete assembly with outer line bellows modified per SK4058-3.

F. On complete assembly with outer line bellows modified per SK4058-4.

G. On complete assembly with outer line bellows modified per SK4058-5.

Flexural Resistance Testing - Evaluation

The factors influencing pressurized flex line bending resistance will be evaluated in this series of tests.

Three non-jacketed flex lines of the configurations shown on Page 53 will be tested. These three configurations (A, B and C) will be identical except for line diameters and length.

Tests will be set-up as shown in Figure 1a (Page 54) and data shall be recorded on data sheet per sample herein shown.

Each of the three (3) configurations will be deflected in increments of one inch during parallel offset tests and in increments of five (5) degrees during angulation tests. For each increment of deflection, pressures from 0 to 150 psig shall be applied internally in 10 psig increments. Thus 16 force readings shall be generated for each increment of motion.

Force versus deflection curves shall be made for each increment of deflection for both test set-ups.

Ruggedness Testing

This testing is designed to duplicate as nearly as is possible the damage found on V. J. flex lines during the hardware evaluation of Phase I. The tests shall be conducted using the test set-up and fixture described in Figure 2 (Page 55). The shape and size of the striking head of the machine has been determined by analysis of known damage to existing lines which were repaired by AMETEK/Straza.

The testing shall be as follows:

A. Baseline striking tests at 90°, 60° and 30° angles to longitudinal centerline of specimen to determine force in each case to cause measured extent of damage to outer jacket bellows. Approximately 1/8 inch indentation in bellows convolutions. Record on Data Sheet as baseline damage when consistently repeatable damage is attained.

B. Using a force determined in baseline strike tests, strike ten (10) blows at each of the three angles (90°, 60° and 30°) on each of the design improvement specimens SK4058-3, -4 and -5 as applied to outer jacket bellows. Record depth, width and other pertinent data on data sheet.

Thermal Tests

Low Temperature Test

A cryogen spill test shall be conducted to determine the ability of the design improvement materials (nylon and silicone rubber) to withstand low temperature thermal shock of the type which can be encountered in disconnect operations and testing.

A sample of the material will be assembled on a short sample bellows of approximately six (6) inch length, duplicating all pertinent conditions. A thermocouple will be attached to it and liquid nitrogen poured over one-half of the outside of the specimen until that part of the specimen reaches -100°F. At this point, the specimen will be allowed to warm to room temperature. It will then be inspected and any affects of the test recorded. This test will be performed three (3) times on each material to insure accurate data.

High Temperature Test

A high temperature test simulating launch blast temperature will be conducted to determine the ability of new materials (nylon and silicone rubber) used on the outside of a line to withstand such blast temperature. The test will be conducted on a small sample of the material assembled on a short sample bellows of approximately six (6) inch length. A flame generator will be employed and a point along the flame at which the temperature is 1400°F determined. The test specimen with thermocouple attached will be moved to this pre-selected 1400°F position in the flame and held for ten (10) seconds. The temperature on the surface of the specimen will be recorded as well as affects of the test specimen determined from inspection. This test will be performed three (3) times on each material to insure accurate data. See Figure 3 (Page 56) for test set-up.

Salt Spray Testing

A salt spray test shall be conducted on test specimens of bellows six (6) inches long with the SK4058-3, -4 and -5 design improvements. Test shall be conducted on three (3) samples of each in accordance with KSC-STD-164, D Revision.

Vibration and Life Cycling Testing

The design improvements which are depicted in SK4058-3, -4 and -5 along with the removable braid design change do not appear to be configurations which would alter the ability of a flex line to withstand flexure stress or the vibration stresses. If at any time during the Phase II program it is considered that data developed would tend to invalidate this assumption, then vibration testing will be proposed to be run in accordance with KSC-STD-164D levels. Cycle life flexure tests could be proposed (if deemed desirable) on the basis of known line motions and life expectancy.

3.1.4.6 Documentation

A test log shall be kept by the testing engineer, listing the following minimum information and any other deemed pertinent:

A. Date of test and specimen identification.

B. Names of testing personnel and others present to observe test.

C. Brief description of test set-up.

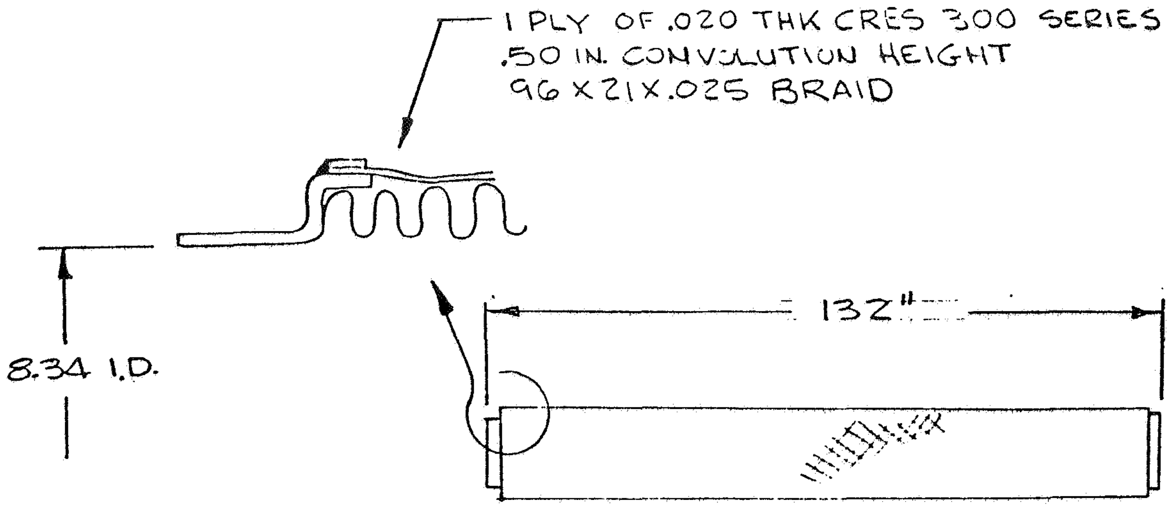
D. Test results, damage, condition of specimen as compared to the condition prior to test.

E. Any circumstances or conditions which might affect test results in any way.

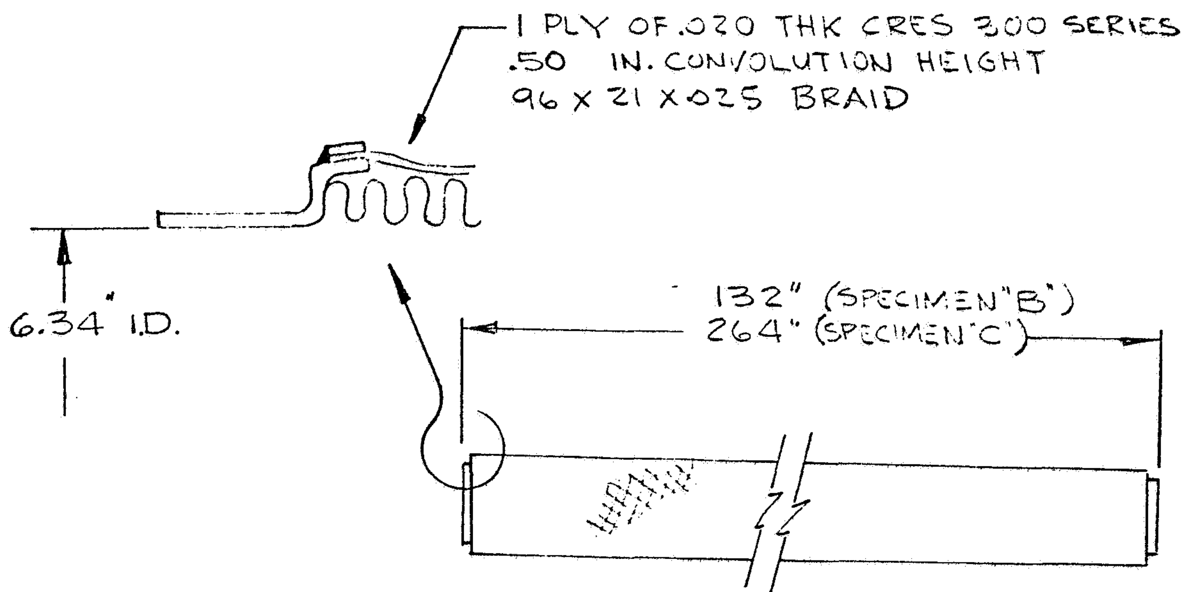
Both the test engineer and the project engineer shall sign the test log entries after each test.

Photographic evidence (polaroid, if possible) shall be made of each test set-up prior to each test run. A photograph shall be made of the specimen following each individual test. In the case of thermal testing, after childown; in the case of flexure, after flexing cycle; in the case of ruggedness tests, after each blow is struck. The photographs shall be identified with data, type of test, specimen identification and any unusual conditions present.

A test report which will include all the foregoing information will be generated by the project engineer. This report will include all facts and conclusions, obvious and otherwise which the tests generated. In addition, this report will contain a section entitled "Recommendations". This section will contain the collective suggestions of AMETEK/Straza regarding further design improvements which are the results of the testing program.




SPECIMEN "A"

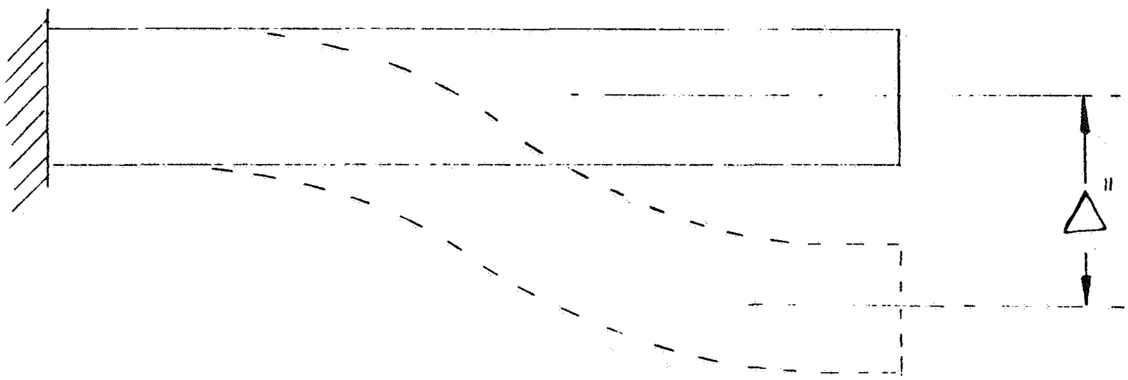



SPECIMEN "B" & "C"

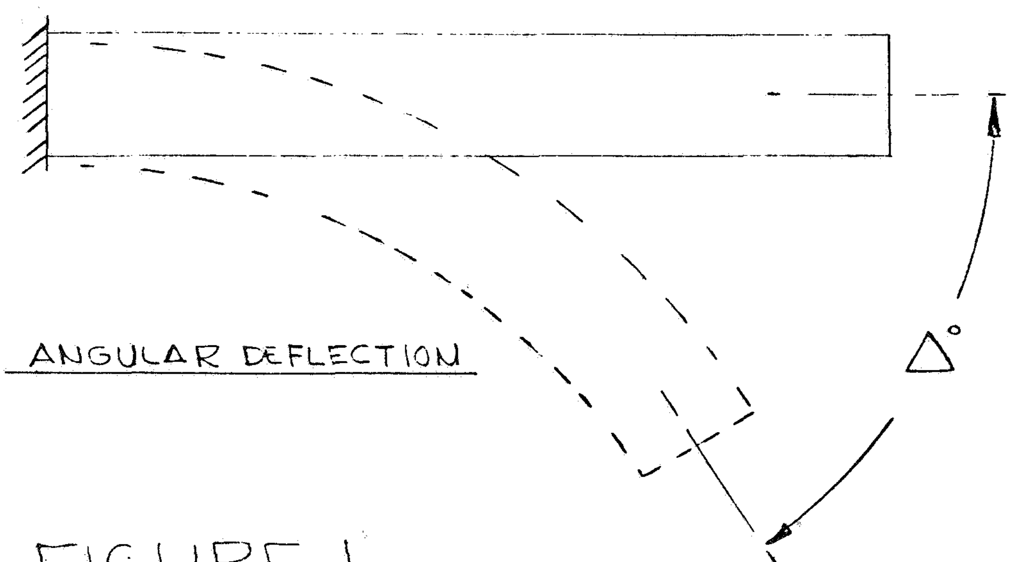
(TEST SPECIMENS FOR FLEX RESISTANCE EVALUATION)

Test Specimen for Flex Resistance Evaluation

TEST SETUPS FOR FLEX RESISTANCE EVALUATION

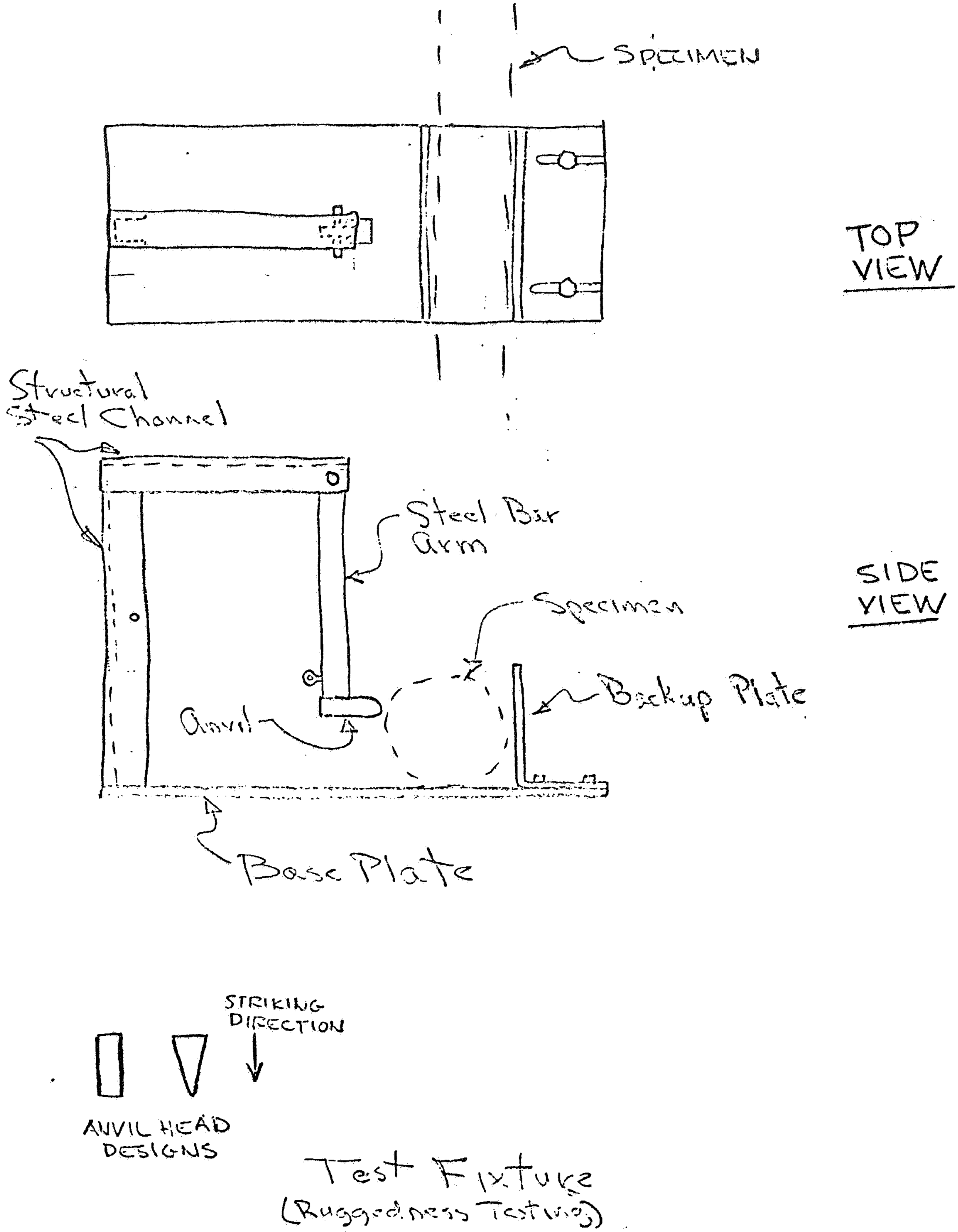



PARALLEL OFFSET DEFLECTION

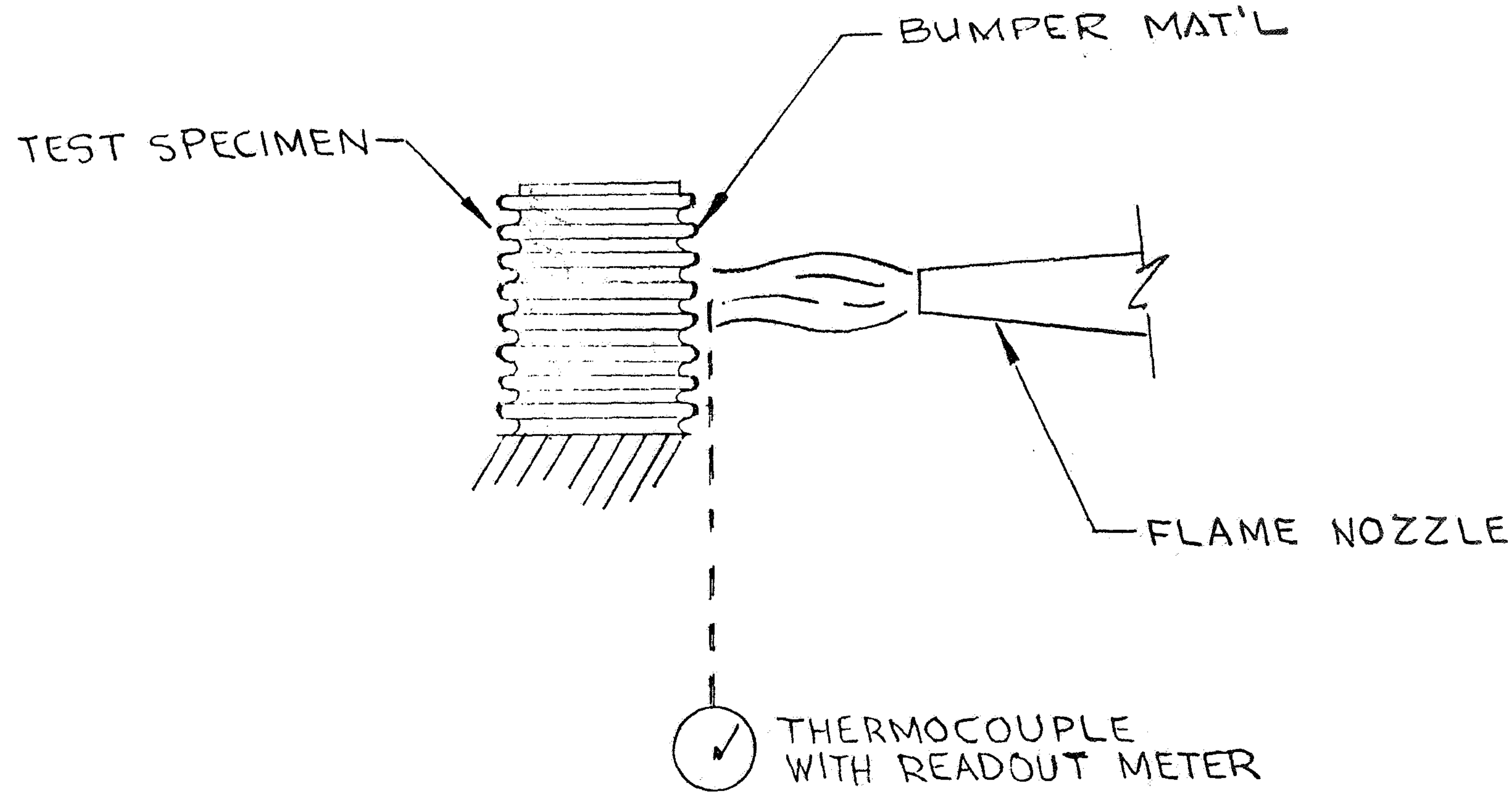



ANGULAR DEFLECTION

FIGURE 1a
Test Set-ups for Flex Resistance

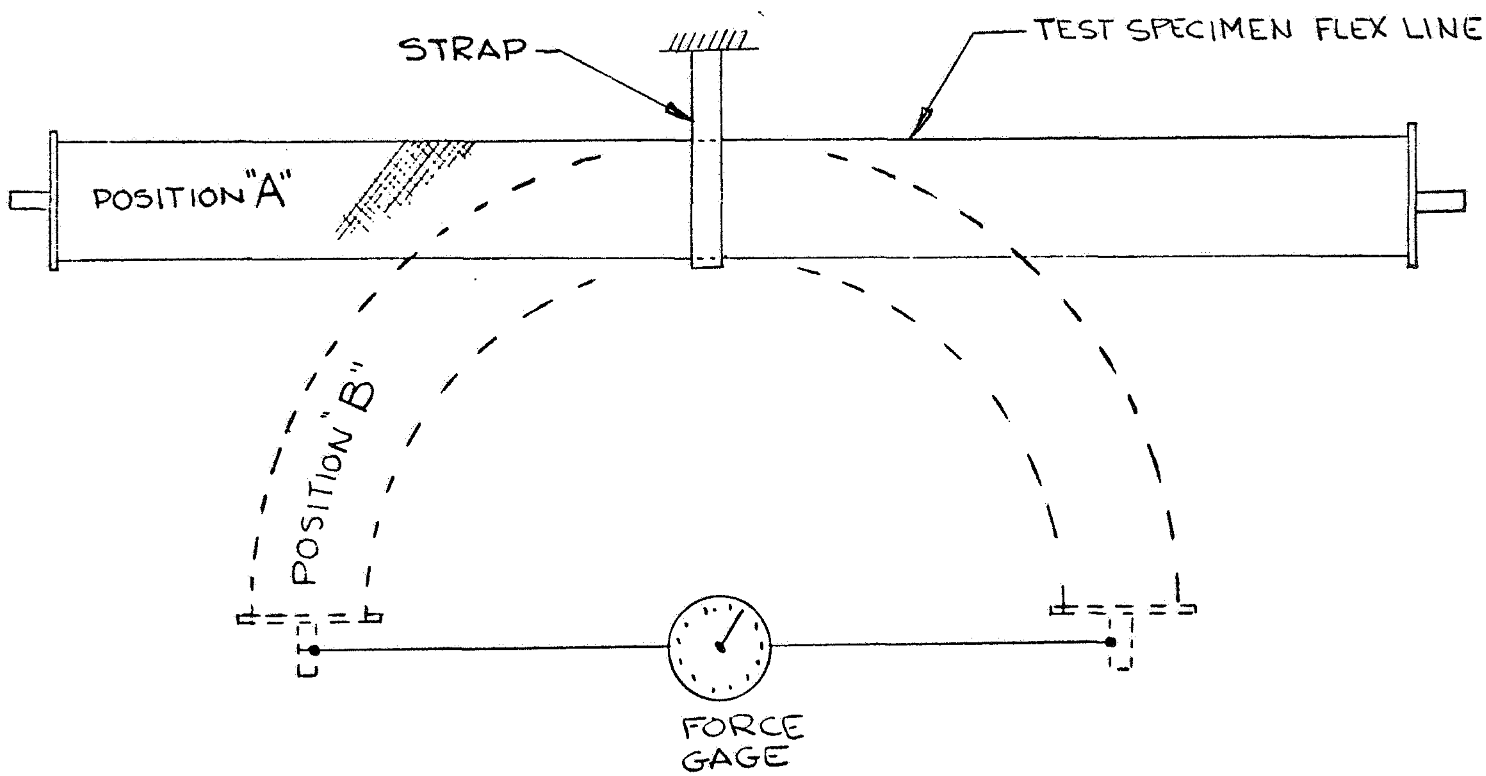



Test Fixture, Ruggedness Testing




HIGH TEMP. TEST SETUP

Test Set-up, High Temperature




Test Set-up, Flexure

## 3.2.0 PHASE II PROGRAM

The Phase II portion of the study was undertaken after all aspects of the Phase I work were analyzed. Therefore the Phase II activities are the logical extension of the investigative efforts of Phase I. The plan to generate more flexible, reliable, rugged and easily repairable flex hoses was the principle effort carried throughout the entire study. The Test Plan, Conclusions, Recommendations and Design Specifications which follow conclude this effort.

### 3.2.1 Introduction

This report contains the results of testing conducted on vacuum and $CO_2$ jacketed flexible metal hoses of the type used to transfer cryogenic fluids. Their design is similar to those in use at Launch Complex 39 at Cape Kennedy. These double wall (bellows within a bellows) hoses are 6 to 8 inches in diameter and 10 to 30 feet long. They incorporated design innovations never previously utilized or tested. These state-of-the-art advancements were designed and developed for the purpose of improving general ruggedness (resistance to in-service impact damage) while either lowering or not affecting the general resistance to bending (flexure) of the hose.

Design improvements consisted of a variety of configurations of energy absorbent bumpers placed about the circumference of bellows convolutions, both with and without wire braid over the assembly. Also, a non-welded, removable braid assembly was designed, built and evaluated.

Testing of the ruggedness improvement device in its various forms consisted of (a) flexural resistance evaluation to determine the bending loads of a hose with and without the protective devices, (b) ruggedness tests using a unique localized load input machine developed for this program, (c) salt fog environmental test to evaluate protective materials used in such an atmosphere, (d) low temperature tests to evaluate the effects of short-time exposure of the protective devices to cryogenic temperatures and (e) high temperature tests to evaluate resistance of the protective device materials to short time exposure to estimated launch blast effects.

In addition to the foregoing, a separate set of tests was run on state-of-the-art flex hoses while pressurized to determine change in resistance to bending due to changes in type of flexure, hose diameter, hose length and pressure.

A. The high temperature test ($1400^{\circ}F$ for 10 seconds) clearly showed the Teflon material as superior; it was the only protective device not visibly affected. The others varied from full ignition for the molded silicone rubber bumpers to slight charring on the RTV "cured-in-place" silicone rubber.

B. The flexural resistance of a V.J. hose with the protective devices installed in lieu of the normal outer jacket braid was approximately the same as a conventional V.J. line with braid. The teflon bumper strips allowed the lowest bending load average of 46.5 pounds through $180^{\circ}$ arc, whereas the same line without protective devices but with braid on the outer jacket averaged 47.5 pounds through $180^{\circ}$ arc.

C. The general flexural resistance tests of various flexible line assemblies with different lengths, diameters and bending modes, indicated that while the difference in bending resistance is greater (73% more) for an 8 inch line than a 6 inch line in a $45^{\circ}$ arc, it is the same for both lines (525 pounds) for 12 inch of parallel offset deflection when lines are pressurized to 150 psi and are all the same length.

D. All of the protective devices withstood the low temperature and salt fog testing without significant effects. The molded silicone rubber strips afforded slightly better impact resistance than the RTV silicone rubber "cured-in-place" about the convolutions of the bellows. However, all the material/configuration combinations reduced the depth of indentation of an impact blow to the convolution ranging from 38% to 55% better than a bellows protected by braid alone.

E. Conclusions on the results of the testing of the protective devices, although definite as to usefulness and practicality, must remain somewhat tentative as to exact design configuration, selection of the energy absorbent unit and its material. No single material or shape stands alone on the basis of this testing program as the best all-around. The resistance to bending should be lowered for any of the protective devices to be ideal. These conclusions point up four major facts: (1) further development is required of the protective devices relative to their exact configuration in order to assure the lowest possible resistance to bending, (2) procurement specifications can be generated such that flex lines incorporating the features of the protective devices could be designed, produced and delivered for application to Launch Complex 39 needs, as presently exist. Minor adjustments in the configuration of the protective devices can effect better flexural properties and greater impact protection. (3) The recommended design is an outer jacket bellows having the RTV Silicone

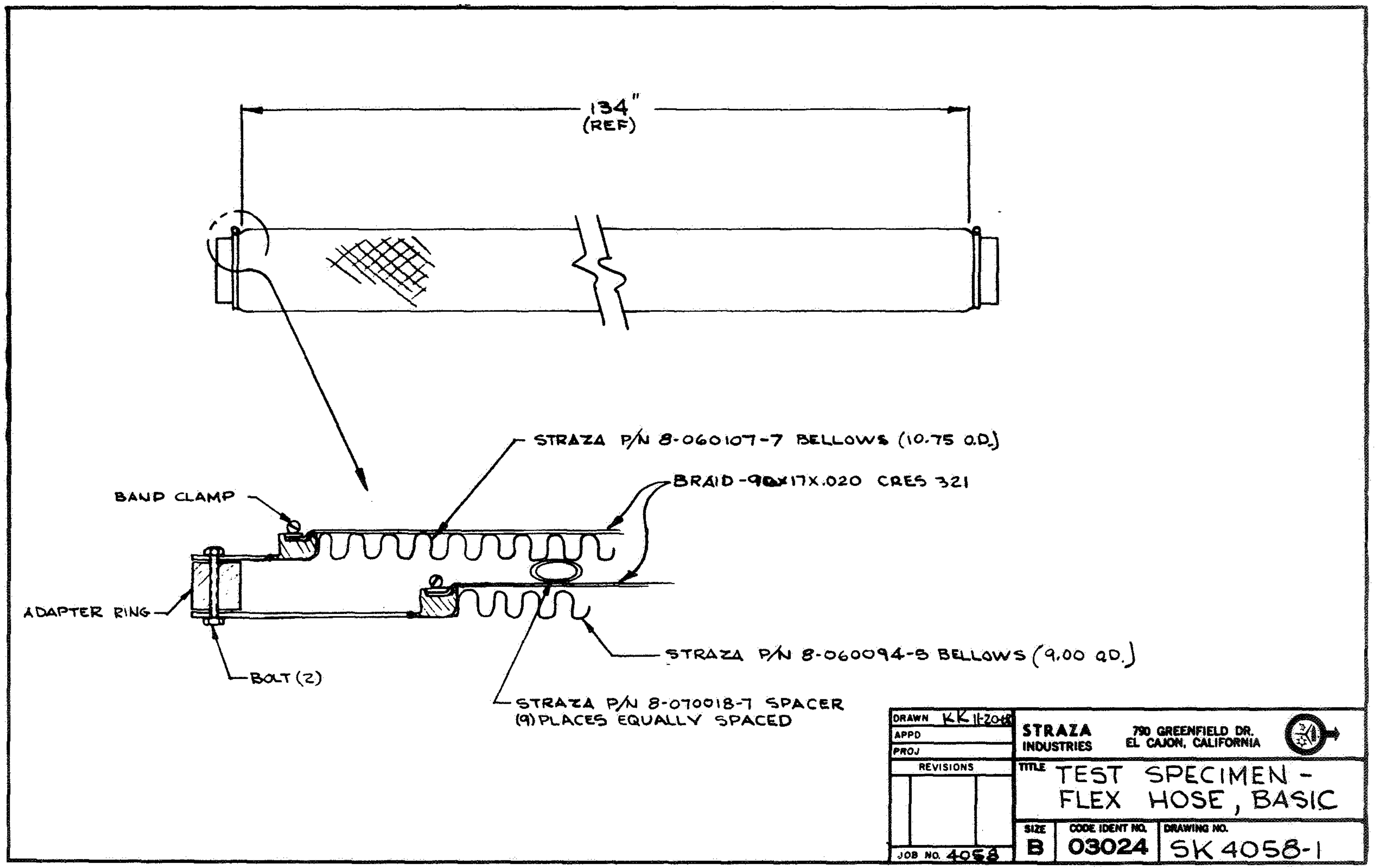
Rubber bumpers molded to the convolutions and also having an optional removable braid sheath for the best combination of protection depending on flexural requirements of the specific usage. If the line were to be used where great ruggedness was imperative but flexural resistance was a secondary consideration, then the braid would be used. If low bending loads were more important, then the flexural resistance could be reduced approximately 20% by braid deletion on the outer jacket bellows. (4) Since the hardware used for development was nearly identical to that which was designed for launch support (fuel and vent) at Launch Complex 39, other applications such as aircraft fueling, LNG loading, etc., might require other design features than the tested improvements described.

### 3.2.2 Phase II Test Report

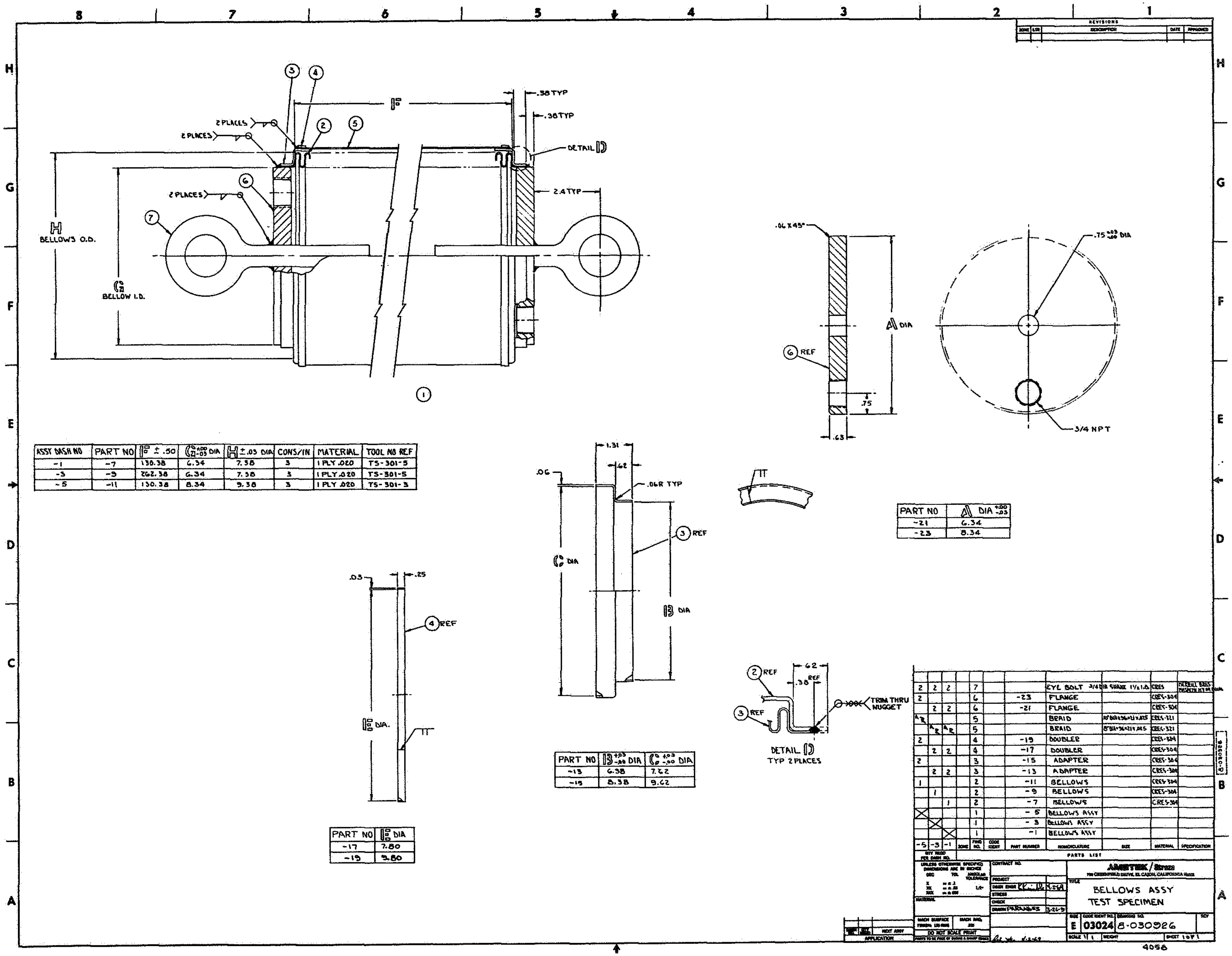
This document describes the results of AMETEK/Straza's "Design Verification Test Procedure, Vacuum Jacketed Flex Hose", Number 8-480088. This testing program was the major item of Phase II of the Vacuum Jacketed Umbilical Lines Technology Advancement Study, Task II, Sub-task 1. It was the intent of this testing program to evaluate certain advances in state-of-the-art technology relative to design of flexible metal hoses for use as cryogenic transfer lines. Since state-of-the-art advancement was the major goal of the overall study program, of which this is a part, certain value judgements are contained in the Test Results and Test Data sections of this report.

#### 3.2.2.1 Item Description

The basic design of the test items is vacuum jacketed flex hose NASA J75M09304-13 (AMETEK/Straza P/N 8-030140-3). This basic configuration was altered slightly as shown on the accompanying drawings SK4058-1 and 8-030926 to facilitate testing. On SK4058-1 it can be seen that the double wall construction is one bellows within another held concentric to each other by a series of tubular polytetrafluorethylene (Teflon) stand-offs. The inner and outer lines consist entirely of annular corrugated CRES type 316L, .010 thick (outer jacket) and .016 thick (inner) material. The tubular CRES type 321 braid covering each bellows is attached only at each end of the line by a band clamp to facilitate testing observation. An adapter ring at each end of the line is the only structural member attaching the two bellows and braid assemblies. There is no seal between the two bellows since no test using this line calls for pressure changes.




AMETEK/Straza Drawing SK4058-1 Test Specimen




AMETEK/Straza Drawing 8-030926

For tests involving pressurization, the three configurations represented on Drawing 8-030926 were used. This is a single wall bellows with tubular braid over its length with welded attachments. Two versions of this line are 11 feet long, one having a 6.34 inch diameter, the other an 8.34 inch diameter. The third version is 22 feet long and has a 6.34 inch diameter. All three lines are .020 inch wall type 304 CRES material.

The total of four configurations of flex hoses so far described fulfilled the needs for the following tests:

A. Flexural Resistance, Design Proof (SK 4058)

B. Flexural Resistance, Evaluation (8-030926)

C. Ruggedness (SK 4058)

For the following tests, short bellows segments approximately one foot long of the same basic design as the outer jacket bellows shown on SK4058 were used.

D. Salt Fog

E. Low Temperature

F. High Temperature

3.2.2.2 Applicable Documents

The following documents of the revision noted were utilized as part of this program in order of precedence.

| Number and Description | Source |
|---|---|
| 8-480088 Design Verification Test Procedure | AMETEK/Straza |
| KSC-STD-164D Environmental Test Methods | John F. Kennedy Space Flight Center |

3.2.2.3 Tests Performed

3.2.2.3.1 Flexural Resistance Design Proof

Test Requirement

This test was performed to determine the specimen's resistance to movement from the straight position through an arc of 180°.

Test Procedure

The test specimen was installed in the test fixture as shown in Flexure Test Set-up, Page 66, Position A. The inner and outer line and annular space were at room temperature and atmospheric pressure. The test consisted of moving the specimen in an arc of 180° from Position A to Position B and measuring the force in pounds to effect this movement at the 180° position. The specimen was then bent in the reverse direction to a 180° arc, the same force reading taken, then rotated about its longitudinal axis 90° and the complete preceding procedure repeated. This test was conducted on the different test specimen configurations as follows:

A. Complete hose assembly as shown in SK4058-1, (Page 67).

B. Complete assembly with outer line bellows modified per SK 4058-5 (Page 70) and no outer braid.

C. Complete assembly with outer line bellows modified per SK 4058-4 (Page 72) and no outer braid.

D. Complete assembly with outer line bellows modified per SK 4058-3 (Page 74) and no outer braid.

E. Inner line only with braid.

F. Inner line only without braid.

G. Outer jacket bellows only without braid.

Test Results

Averaged forces required to bend the various hose configurations A through G preceding are as follows:

A. 47.5 pounds

B. 46.5 pounds

C. 57.7 pounds

D. 51.2 pounds

E. 50.0 pounds

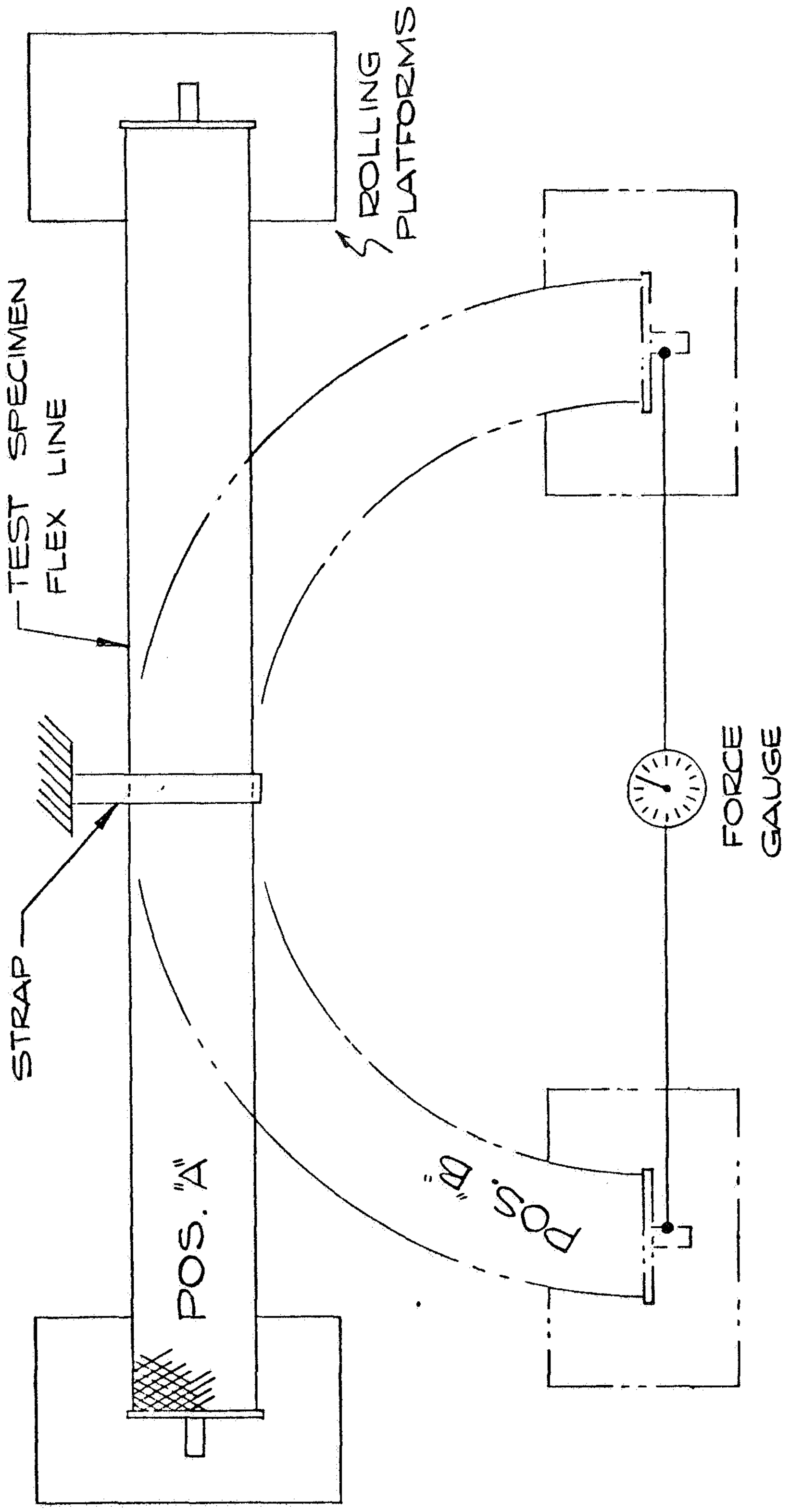
F. 17.7 pounds

G. 18.7 pounds

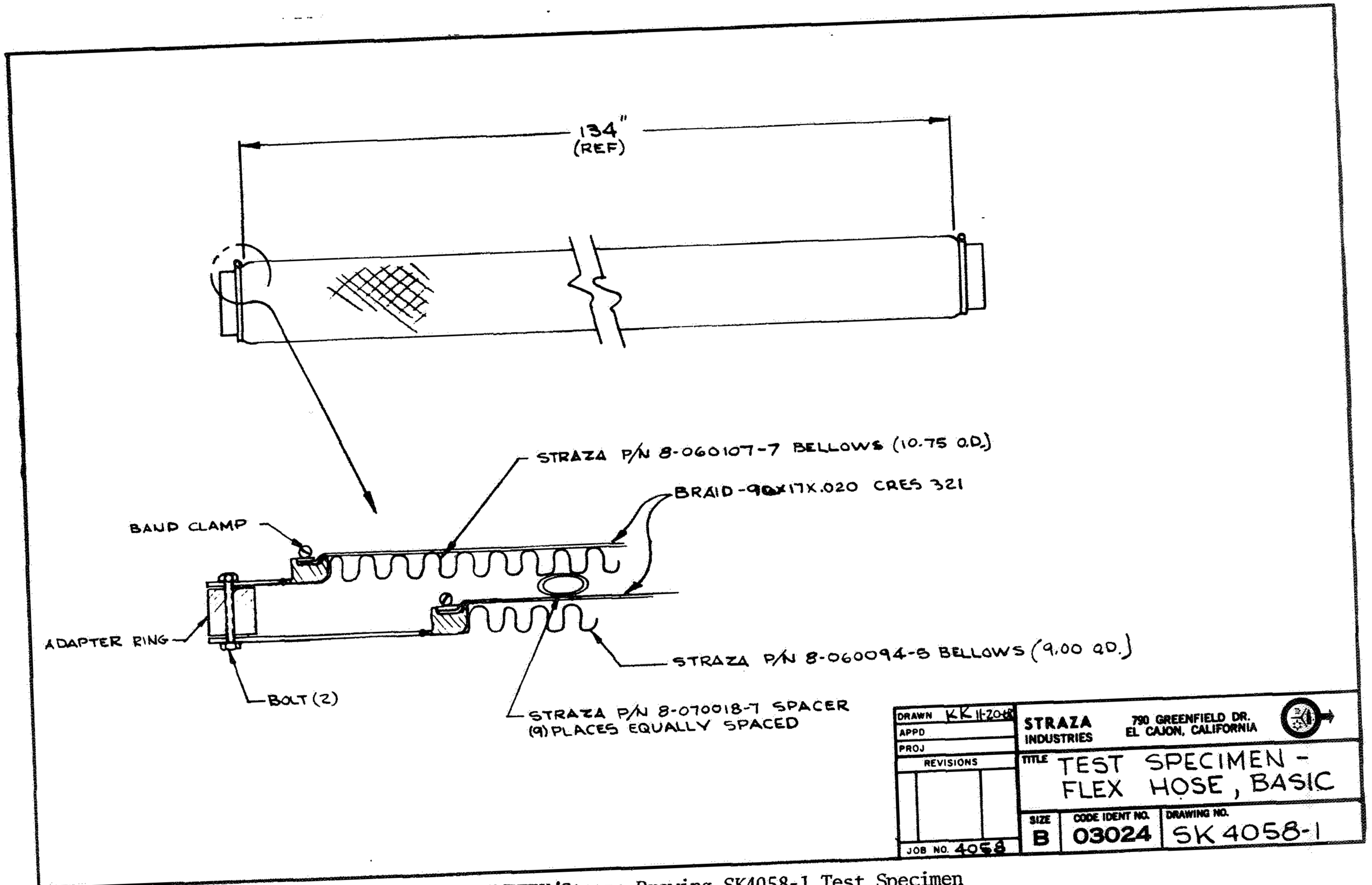
These test results clearly show that no great change in flexural resistance in an un-pressurized hose of this configuration takes place until the braid is removed (F & G). Substituting the various protective devices for the outer jacket braid made only minor changes in bending resistance. One exception to this appears to be C above, (the molded silicone spacers) which interfered with each other at the inner radius bend. They produced a 21.5% increase in flexural resistance. However, it may be noted that a slightly narrower shape might nullify this effect. At any rate, the test results do tend to indicate that the protective devices have the potential of replacing outer jacket braid with no significant change in bending loads.

## Test Data

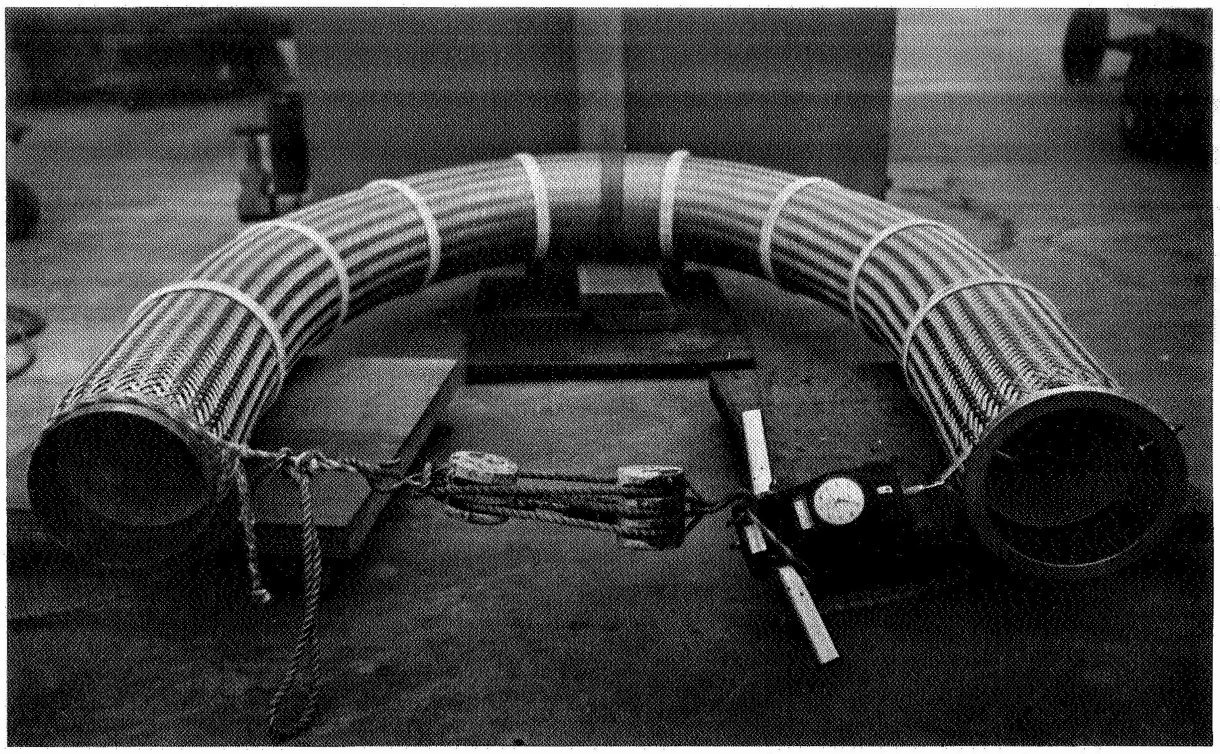
The following Flexure Test Set-up shows the basic test set-up while the figure on Page 67 shows the basic specimen. Following these are, in turn, each figure with a data sheet showing test results. After this data follows photographic documentation of several phases of the testing.



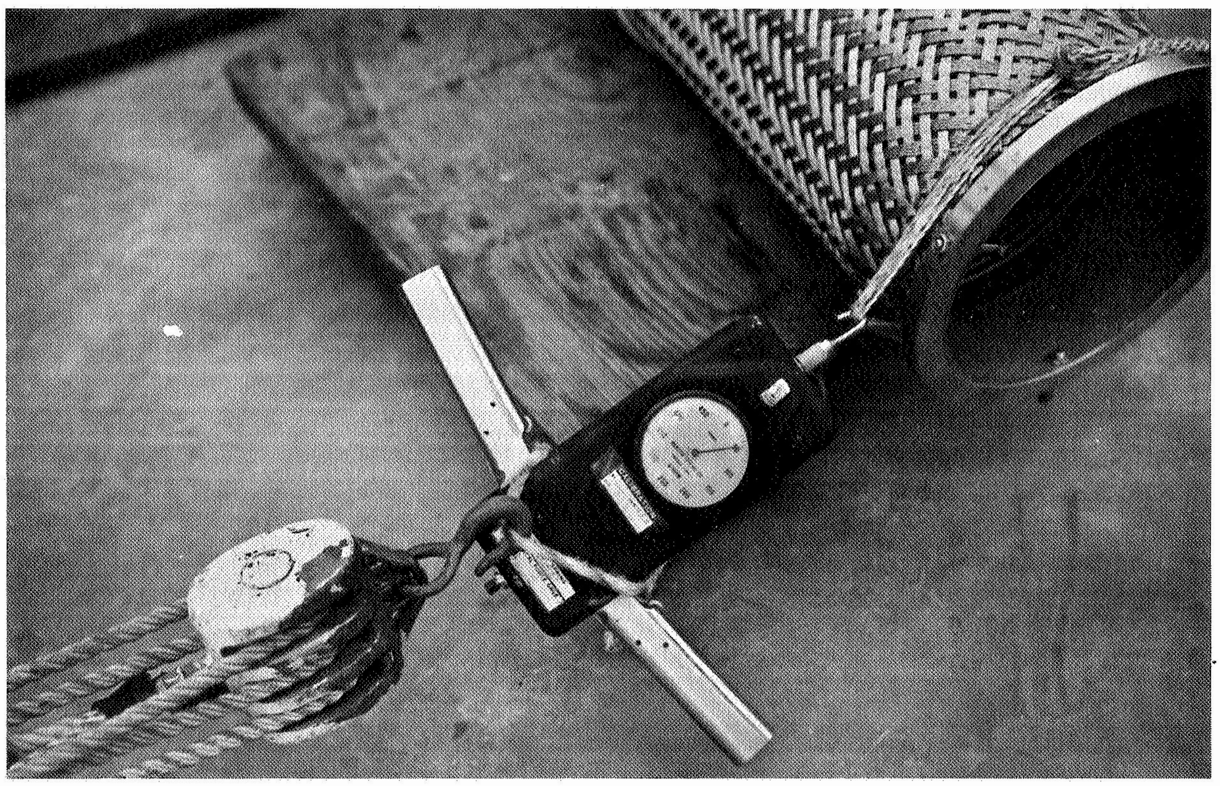

Test Set-up, Flexure




AMETEK/Straza Drawing SK4058-1 Test Specimen



Test Setup For Unpressurized Flexure Of Flex Hose
With Inner Line And Braid With Stand-Offs



Force Gage Attachment For Unpressurized Flexure
Evaluation Of Flex Hose Improvements

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Flexural Resistance Date of Test 12 September 1969

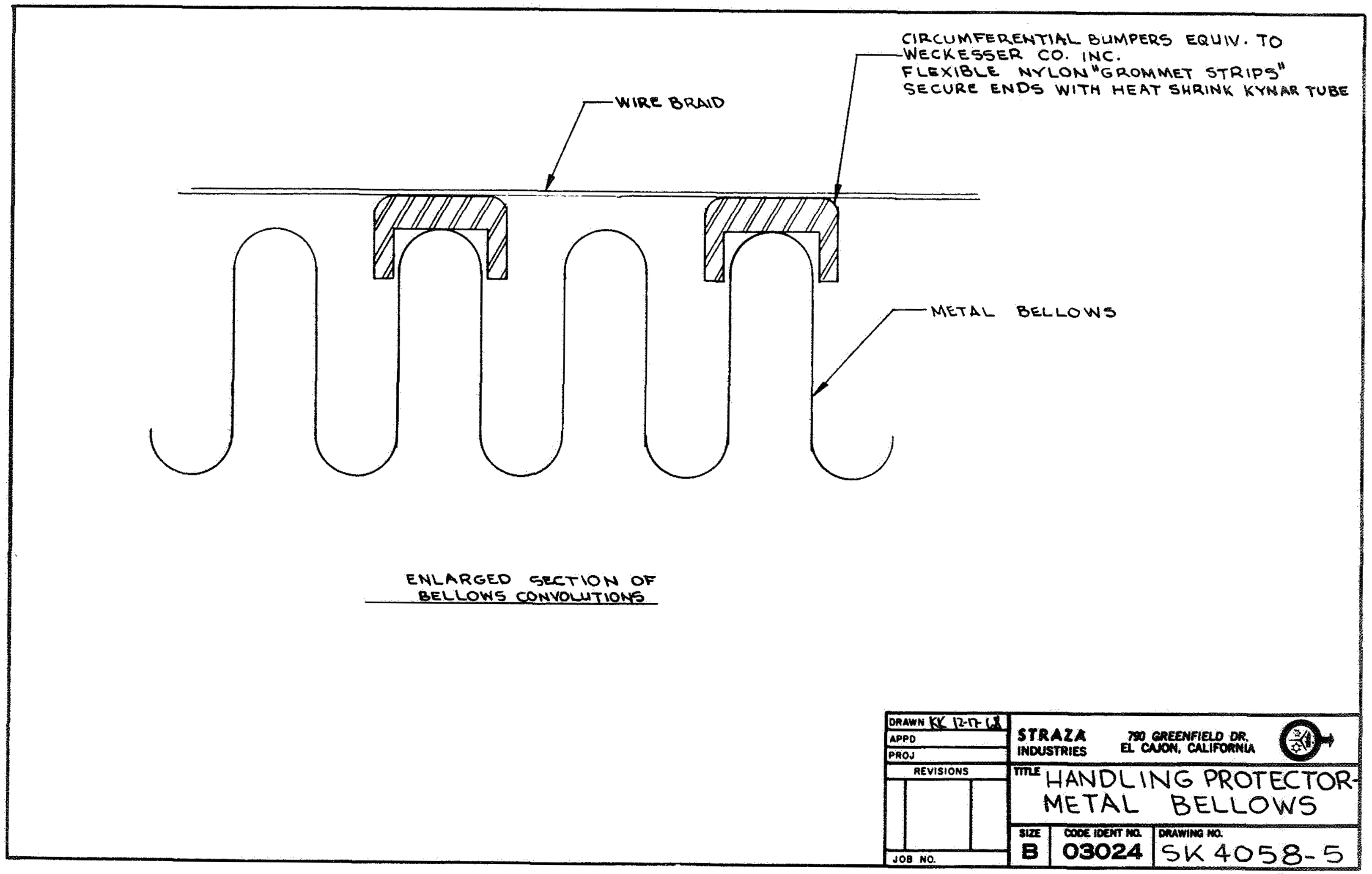
Part Name Flex Line Test Procedure 8-480088

Line Configuration Complete Line Assembly with Outer Braid

| | Force Required | Remarks |
|---|---|---|
| 1. Flex from A to B | 38 Lbs | Average - 47.5 Lbs |
| 2. Flex from A to Rev B | 55 Lbs | |
| 3. Rotate Line $90^{o}$ | | |
| 4. Flex from A to B | 45 Lbs | |
| 5. Flex from A to Rev B | 52 Lbs | |

Test Technician /s/ L. Mc Knight

Test Engineer /s/ J. Martinez




AMETEK/Straza Drawing SK4058-5 Handling Protector

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Flexural Resistance Date of Test 11 September 1969

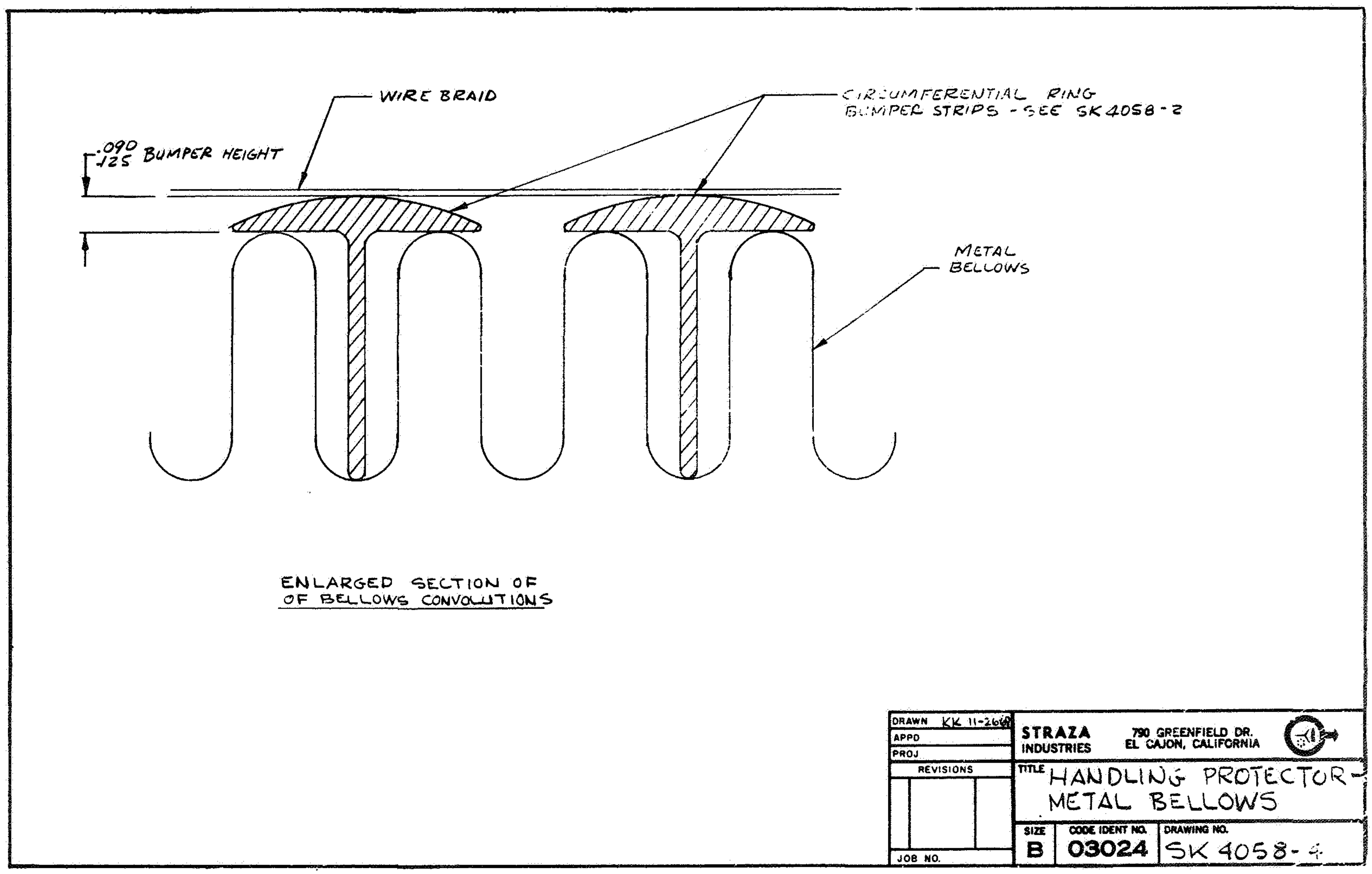
Part Name Flex Line Test Procedure 8-480088

Line Configuration Without Outer Braid - Teflon Spacer SK4058-5

| | Force Required | Remarks |
|---|---|---|
| 1. Flex from A to B | 40 Lbs | Average - 46.5 Lbs |
| 2. Flex from A to Rev B | 45 Lbs | |
| 3. Rotate Line $90^{\circ}$ | | |
| 4. Flex from A to B | 55 Lbs | |
| 5. Flex from A to Rev B | 46 Lbs | |

Test Technician /s/ L. Mc Knight

Test Engineer /s/ J. Martinez




AMETEK/Straza Drawing SK4058-3 Protective Bumper

## DESIGN VERIFICATION TEST

## TEST DATA SHEET

Type of Test: Flexural Resistance — Date of Test: 10 September 1969

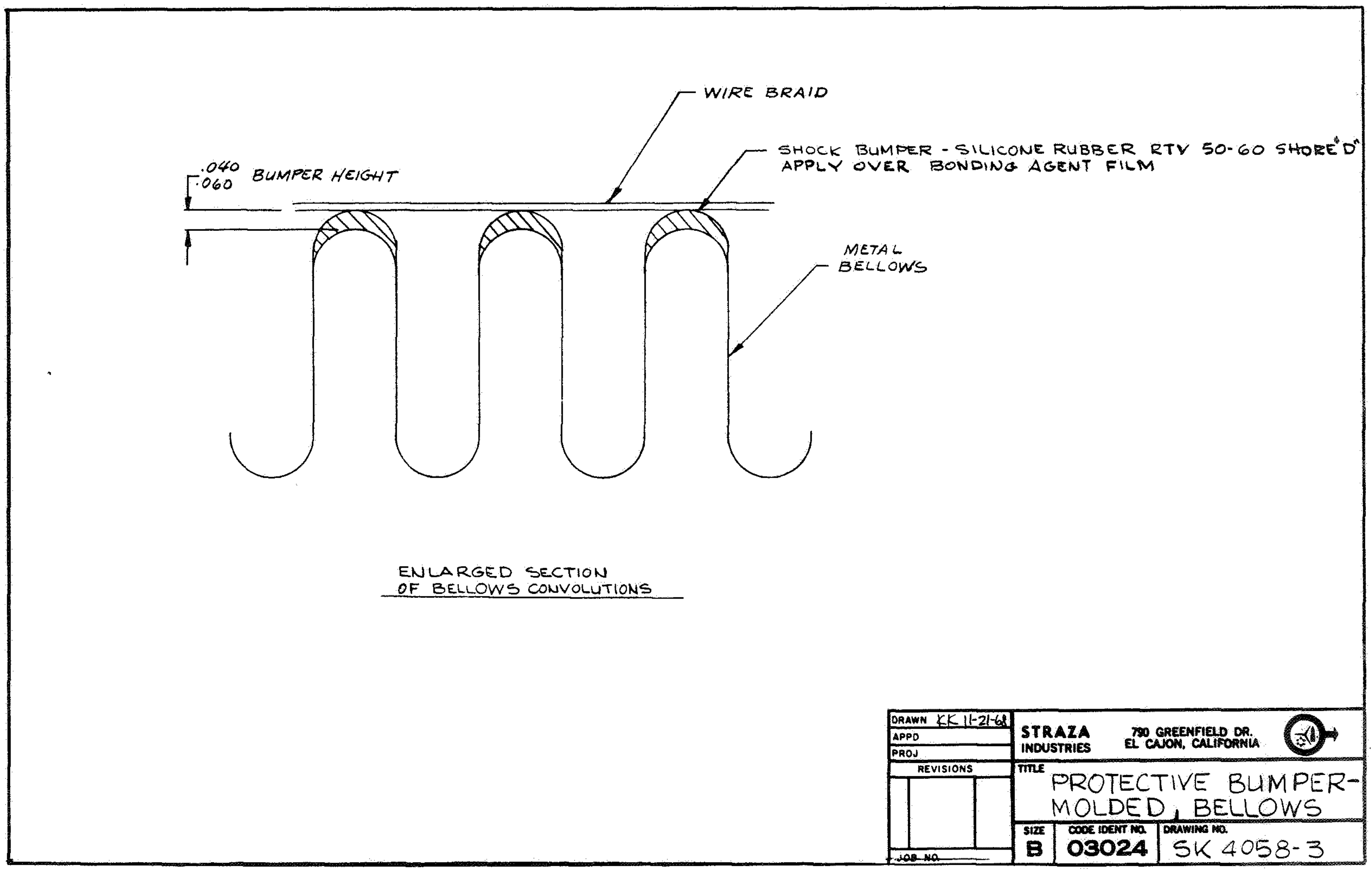
Part Name: Flex Line — Test Procedure: 8-480088

Line Configuration: Without Outer Braid - Silicone Spacers SK4058-4

| | Force Required | Remarks |
|---|---|---|
| 1. Flex from A to B | 70 Lbs | Average - 57.7 Lbs |
| 2. Flex from A to Rev B | 44 Lbs | |
| 3. Rotate Line $90^{\circ}$ | | |
| 4. Flex from A to B | 55 Lbs | |
| 5. Flex from A to Rev B | 62 Lbs | |

Test Technician: /s/ L. Mc Knight

Test Engineer: /s/ J. Martinez




AMETEK/Straza Drawing SK4058-3 Protective Bumper

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Flexural Resistance Date of Test 9 September 1969

Part Name Flex Line Test Procedure 8-480088

Line Configuration Without Outer Braid - RTV SK4058-3

| | Force Required | Remarks |
|---|---|---|
| 1. Flex from A to B | 54 Lbs | Average - 51.2 Lbs |
| 2. Flex from A to Rev B | 50 Lbs | |
| 3. Rotate Line $90^\circ$ | | |
| 4. Flex from A to B | 50 Lbs | |
| 5. Flex from A to Rev B | 51 Lbs | |

Test Technician /s/ L. Mc Knight

Test Engineer /s/ J. Martinez

## DESIGN VERIFICATION TEST

## TEST DATA SHEET

Type of Test: Flexural Resistance | Date of Test: 17 September 1969

Part Name: Flex Line | Test Procedure: 8-480088

Line Configuration: Inner Line Bellows with Braid Only

| | Force Required | Remarks |
|---|---|---|
| 1. Flex from A to B | 45 Lbs | |
| 2. Flex from A to Rev B | 55 Lbs | |
| 3. Rotate Line 90° | | |
| 4. Flex from A to B | 50 Lbs | |
| 5. Flex from A to Rev B | 50 Lbs | |

Test Technician /s/ L. Mc Knight

Test Engineer /s/ K. Kimble

## DESIGN VERIFICATION TEST

## TEST DATA SHEET

Type of Test: Flexural Resistance — Date of Test: 24 September 1969

Part Name: Flex Line — Test Procedure: 8-480088

Line Configuration: Inner Line Bellows Only

| | Force Required | Remarks |
|---|---|---|
| 1. Flex from A to B | 17 Lbs | |
| 2. Flex from A to Rev B | 10 Lbs | |
| 3. Rotate Line $90^{o}$ | | |
| 4. Flex from A to B | 22 Lbs | |
| 5. Flex from A to Rev B | 22 Lbs | |

Test Technician: /s/ L. Mc Knight

Test Engineer: /s/ K. Kimble

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Flexural Resistance - Design Proof Date of Test 9 October 1969

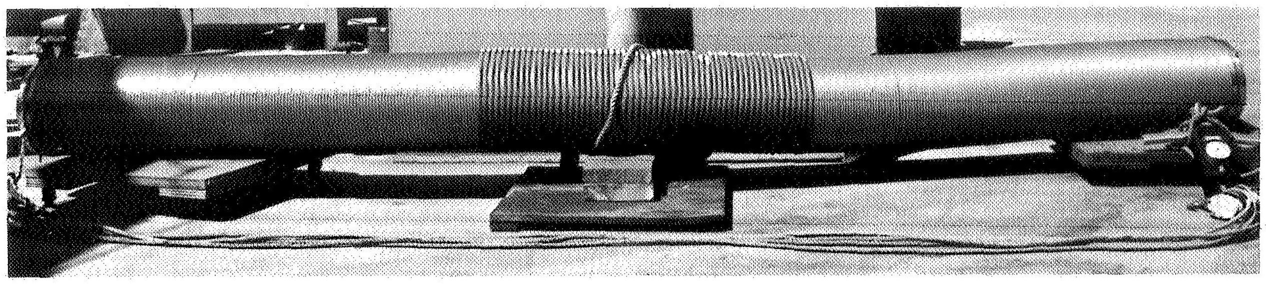
Part Name Flex Line Test Procedure 8-480088

Line Configuration Outer Jacket Bellows Only - No Braid

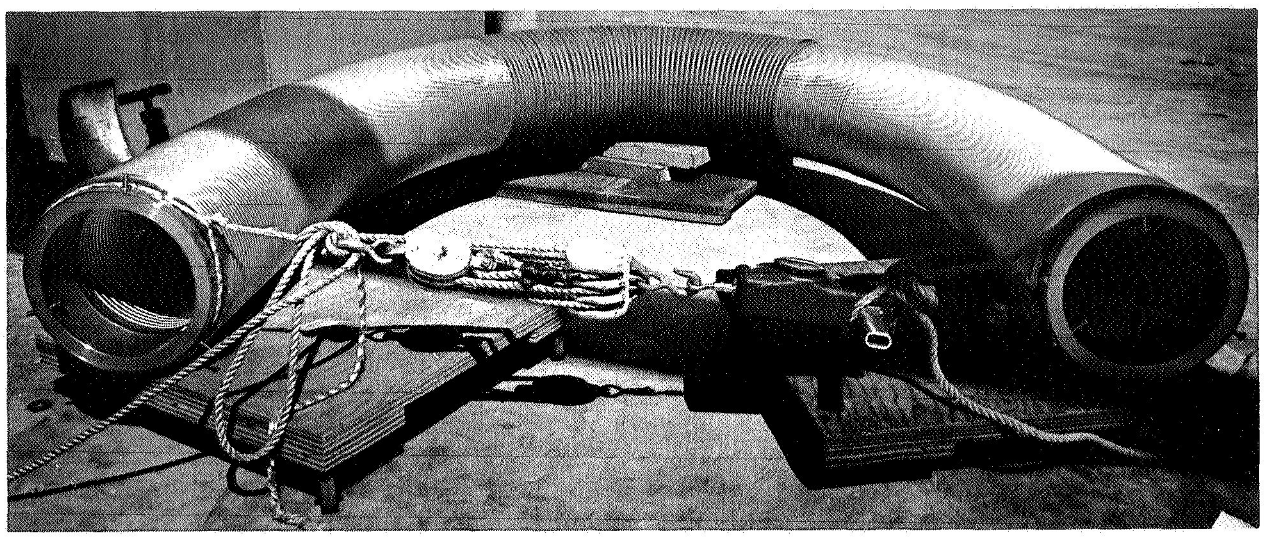
| | Force Required | Remarks |
|---|---|---|
| 1. Flex from A to B | 23 Lbs | |
| 2. Flex from A to Rev B | 15 Lbs | |
| 3. Rotate Line $90^{\circ}$ | | |
| 4. Flex from A to B | 16 Lbs | |
| 5. Flex from A to Rev B | 21 Lbs | |

Test Technician /s/ L. Mc Knight

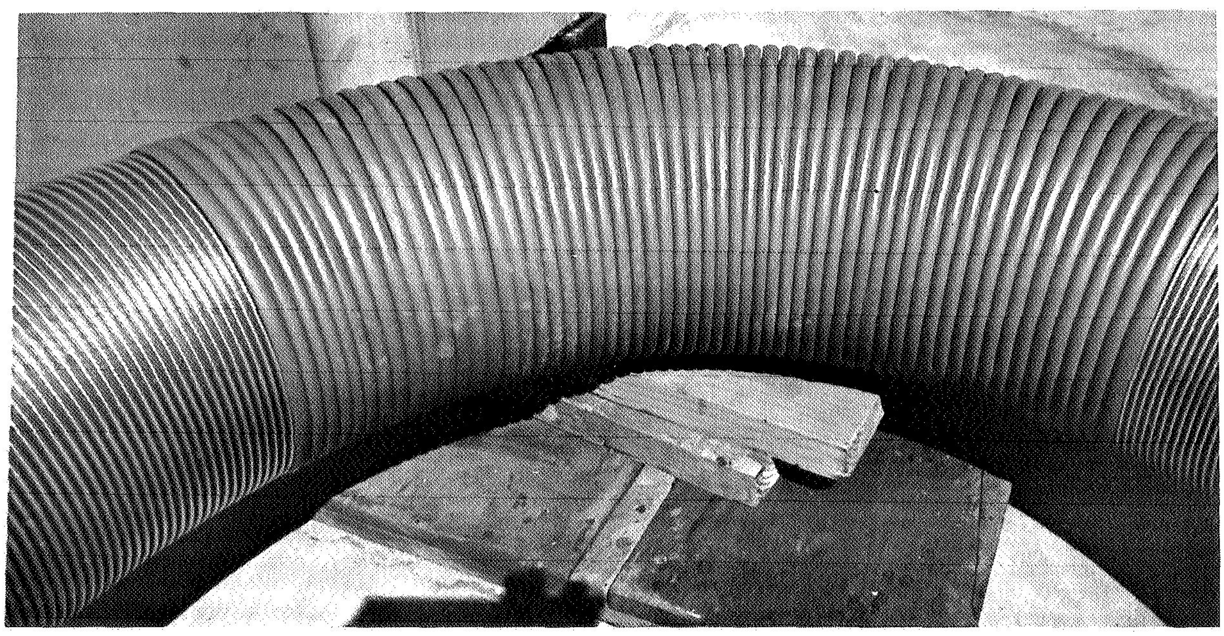
Test Engineer



Flex Hose Test Setup For Protective Devices Prior
To Bending — Molded Silicone Rubber Bumpers

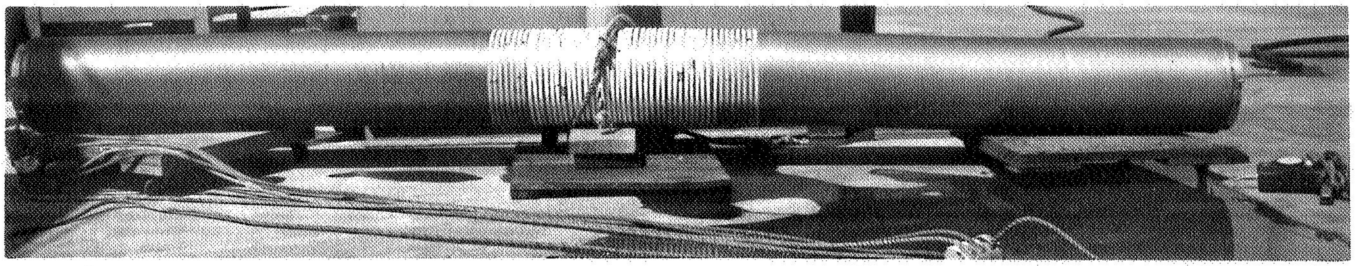


Flex Hose Test Setup For Protective Devices Evaluation
In 180° Bend Condition — Molded Silicone Rubber Bumpers

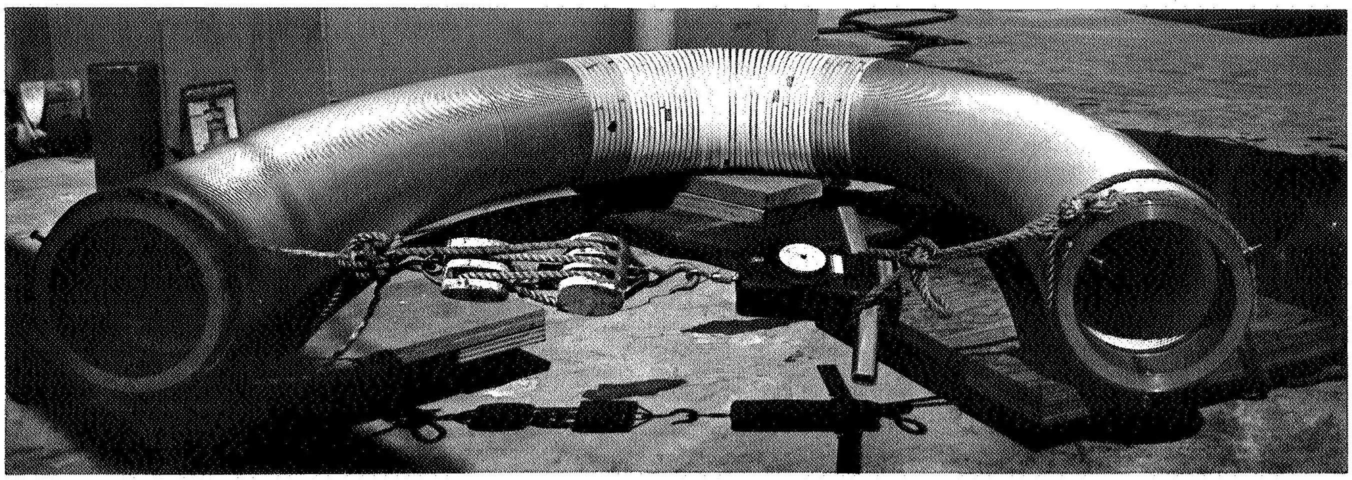


Flex Hose Bent 180° With Silicone Rubber Bumpers Installed —
Note Bumpers Just Touch But Do Not Wrinkle

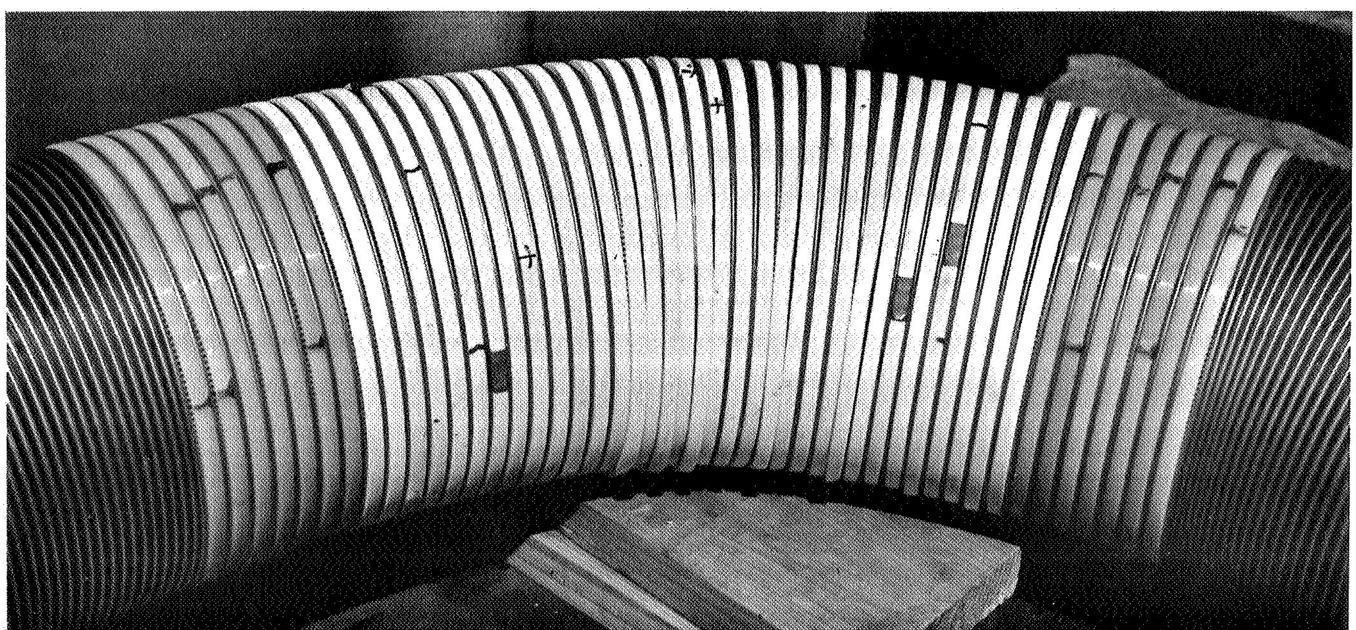
Flex Hose Test Set-up



Flex Hose Test Setup For Protective Devices Prior
To Bending — Nylon/Teflon Bumpers



Flex Hose Test Setup For Protective Devices Evaluation
In 180° Bend Condition — Nylon/Teflon Bumper



Flex Hose Bent 180° With Teflon/Nylon Bumpers Installed —
Note Interferance Overlapping On Inner Radius Of Hose. This
Began To Occur At 160° Bend Angle.

Flex Hose Test Set-up

## 3.2.2.3.2 Flexural Resistance Test - Evaluation

### Test Requirement

This test was performed to determine the test item's resistance to bending, under pressure, through an arc of 45° of angular deflection.

### Test Procedure

Three (3) test items (-1, -3 and -5 on Page 82) were subjected to this test. The test item was installed in a test fixture as shown on Page 83 with one end in the fixed position. The test item was pressurized with water in 10 psi increments from 0 to 150 psig. At each 10 psi increment, the test item was deflected through a 45° angle in increments of 5°.

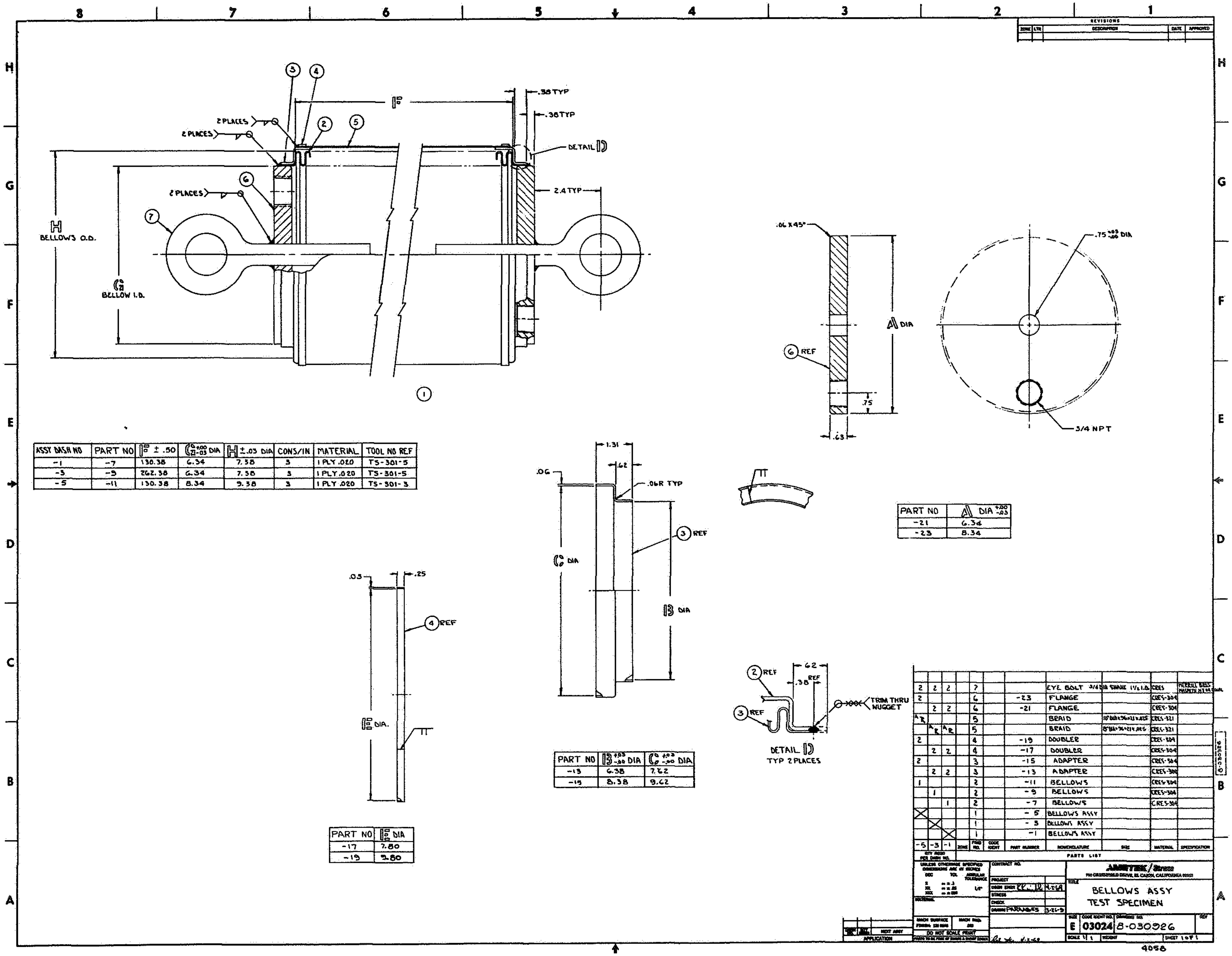
The force required to restrain the test item at each 5° of deflection and at each 10 psi increment was recorded.

### Test Results

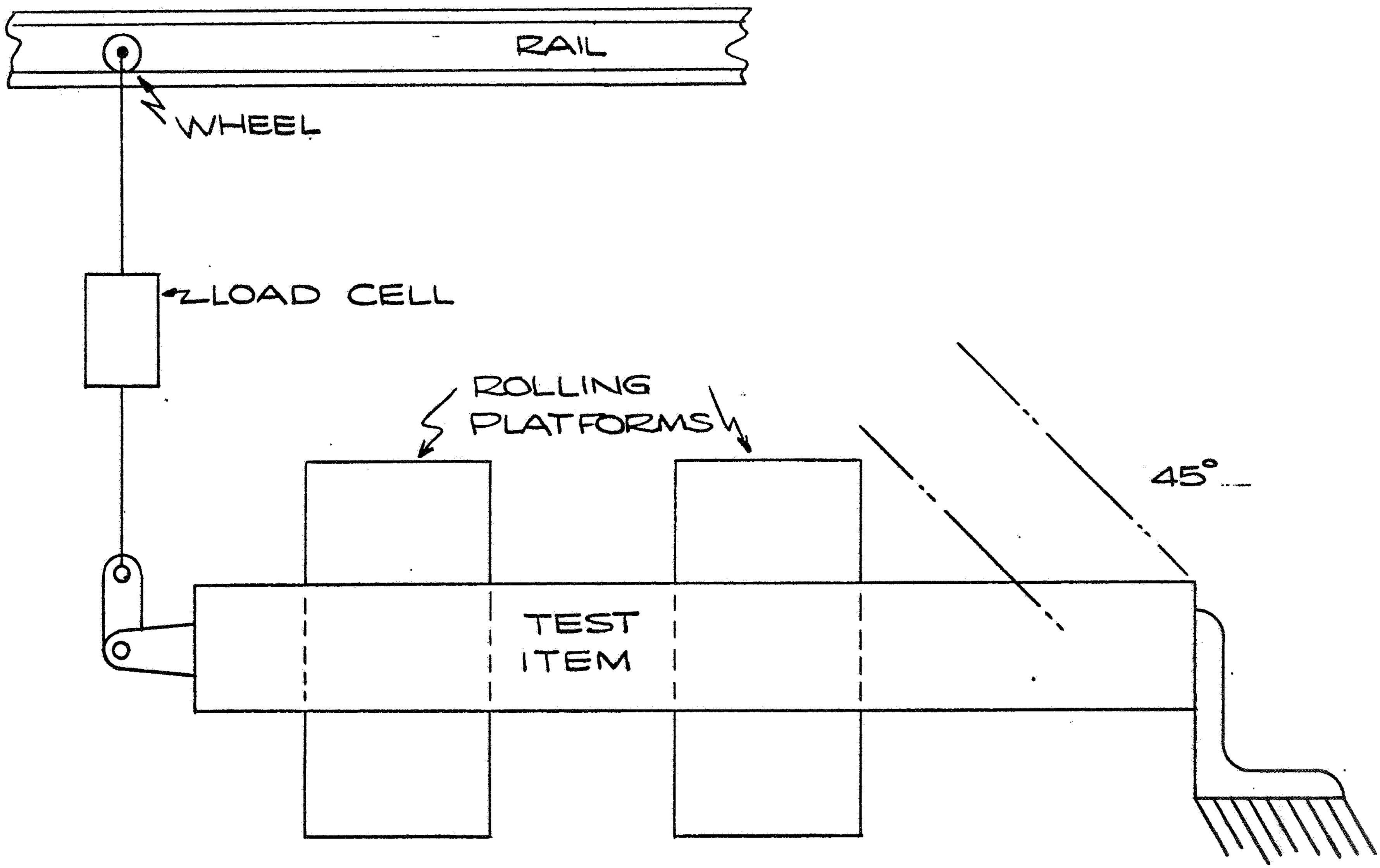
The results of this test as graphically illustrated on the following curves, tend to indicate that for a relatively long, slim hose of the 8-030926-3 (6 inch diameter X 21 feet long) configuration there is very little load created by a small (up to 20°) bending arc. However, for a larger diameter, shorter hose of the 8-030926-5 (8 inch diameter X 11 feet long) configuration an almost linear increase at a much greater rate is produced in bending loads at pressure.

### Test Data

The following data sheets give the bending loads for each 5° of bend increase at each 10 psig increment of pressure increase for each of the three configurations tested. The photographs which follow the data sheets were taken during the testing.

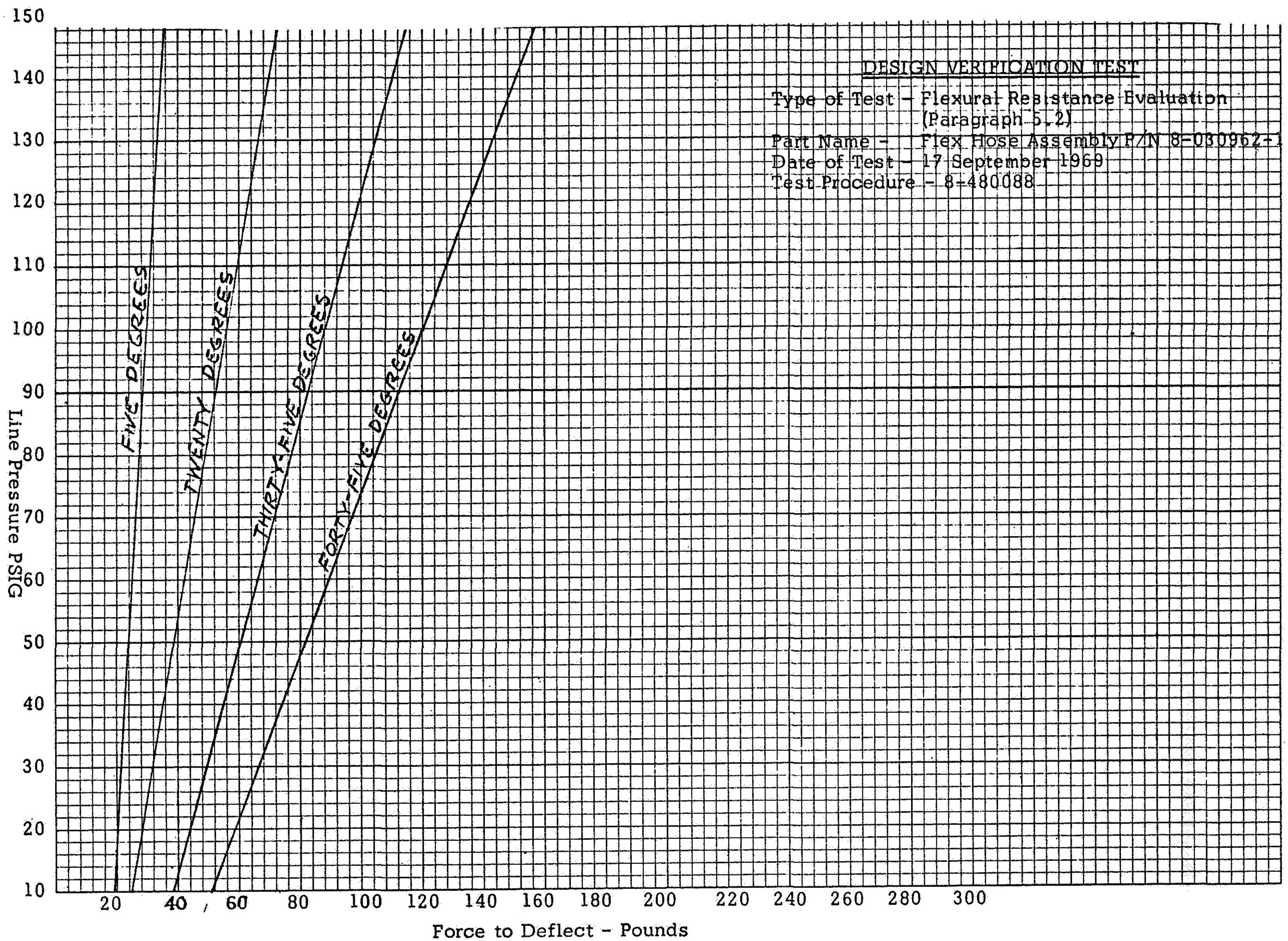


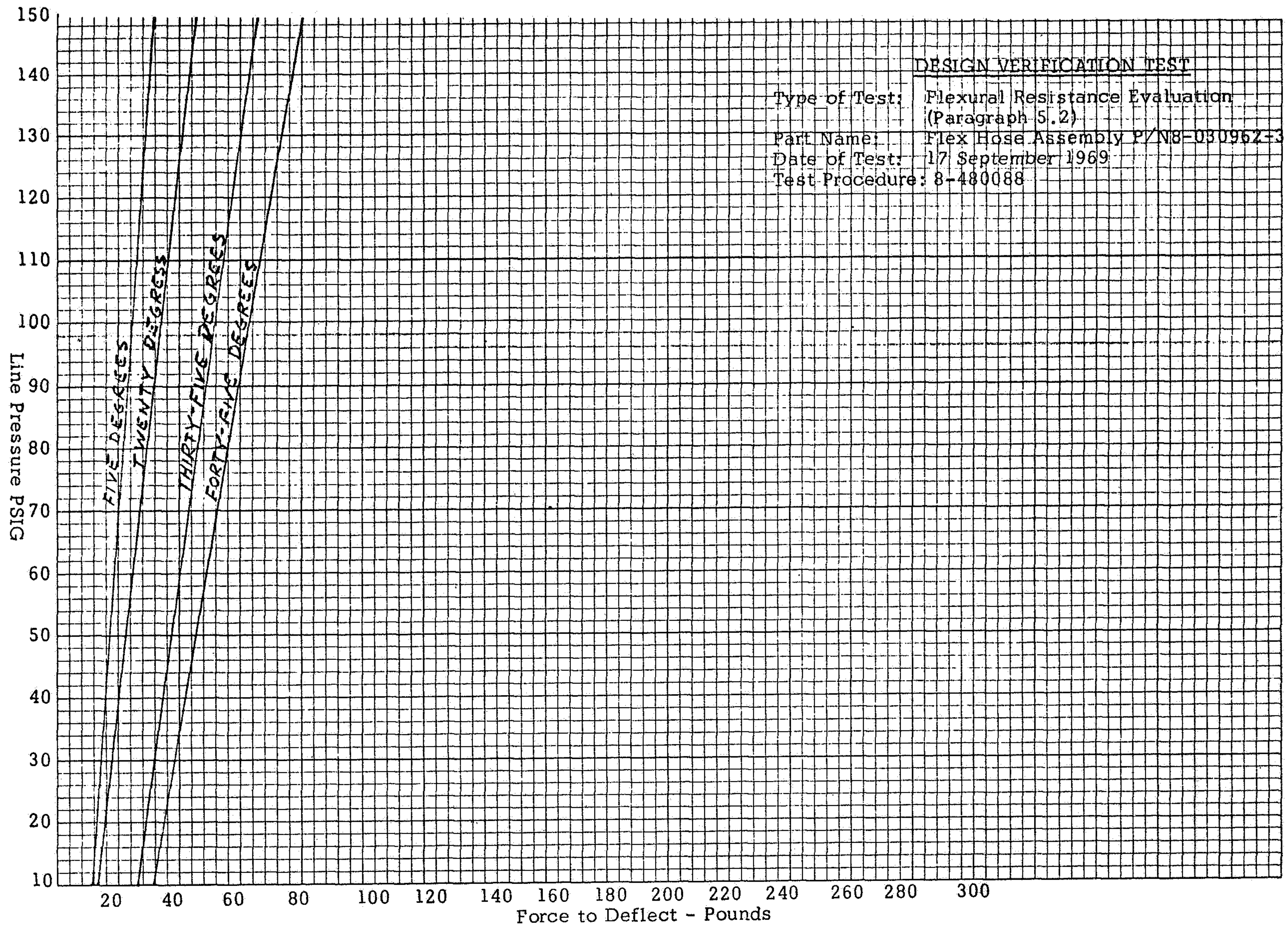

AMETEK/Straza Drawing 8-030936 Test Specimen

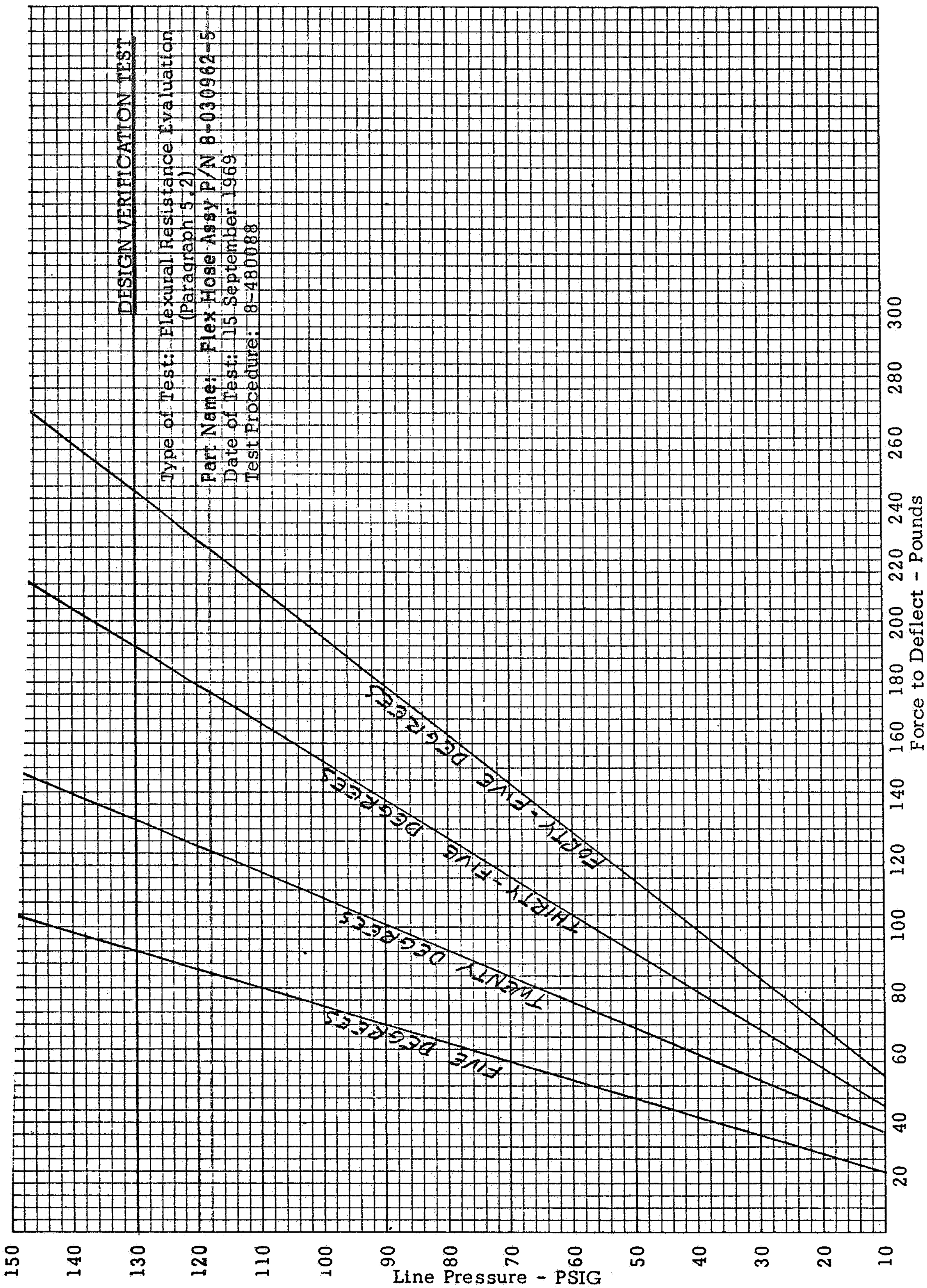



TOP VIEW

Test Set-up, Pressurized Angular Deflection


DESIGN VERIFICATION TEST
Type of Test - Flexural Resistance Evaluation
(Paragraph 5.2)
Part Name - Flex Hose Assembly P/N 8-030962-1
Date of Test - 17 September 1969
Test Procedure - 8-480088
FIVE DEGREES
TWENTY DEGREES
THIRTY-FIVE DEGREES
FORTY-FIVE DEGREES
Line Pressure PSIG
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
Force to Deflect - Pounds


DESIGN VERIFICATION TEST
Type of Test: Flexural Resistance Evaluation (Paragraph 5.2)
Part Name: Flex Hose Assembly P/N8-030962-3
Date of Test: 17 September 1969
Test Procedure: 8-480088
FIVE DEGREES
TWENTY DEGREES
THIRTY-FIVE DEGREES
FORTY-FIVE DEGREES
Line Pressure PSIG
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
Force to Deflect - Pounds



DESIGN VERIFICATION TEST
Type of Test: Flexural Resistance Evaluation
(Paragraph 5.2)
Part Name: Flex Hose Assy P/N 8-030962-5
Date of Test: 15 September 1969
Test Procedure: 8-480088
FIVE DEGREES
TWENTY DEGREES
THIRTY-FIVE DEGREES
FORTY-FIVE DEGREES
20 40 60 80 100 120 140 160 180 200 220 240 260 280 300
Force to Deflect - Pounds
150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
Line Pressure - PSIG

# DESIGN VERIFICATION TEST

## TEST DATA SHEET

Type of Test: Flexural Resistance Evaluation (Para. 5.2) Date of Test: 9/17/69

Part Name: Flex Hose Assembly P/N 8-030962-1 Test Procedure: 8-480088

| Pressure (PSIG) | Deflection & Force | | | Remarks |
|---|---|---|---|---|
| 10 | 5° 18# | 10° 20# | 15° 21# | |
| | 20° 23# | 25° 25# | 30° 28# | |
| | 35° 38# | 40° 50# | 45° 50# | |
| 20 | 5° 20# | 10° 23# | 15° 23# | |
| | 20° 28# | 25° 30# | 30° 37# | |
| | 35° 42# | 40° 50# | 45° 58# | |
| 30 | 5° 20# | 10° 28# | 15° 28# | |
| | 20° 32# | 25° 35# | 30° 40# | |
| | 35° 50# | 40° 60# | 45° 65# | |
| 40 | 5° 28# | 10° 28# | 15° 30# | |
| | 20° 38# | 25° 42# | 30° 50# | |
| | 35° 58# | 40° 68# | 45° 80# | |
| 50 | 5° 28# | 10° 30# | 15° 35# | |
| | 20° 45# | 25° 48# | 30° 55# | |
| | 35° 65# | 40° 80# | 45° 90# | |
| 60 | 5° 28# | 10° 30# | 15° 35# | |
| | 20° 43# | 25° 50# | 30° 65# | |
| | 35° 75# | 40° 90# | 45° 93# | |
| 70 | 5° 28# | 10° 30# | 15° 40# | |
| | 20° 47# | 25° 55# | 30° 68# | |
| | 35° 75# | 40° 88# | 45° 100# | |

| Pressure (PSIG) | Deflection & Force | | | Remarks |
|---|---|---|---|---|
| 80 | 5° 33# | 10° 38# | 15° 45# | |
| | 20° 53# | 25° 60# | 30° 75# | |
| | 35° 85# | 40° 100# | 45° 105# | |
| 90 | 5° 32# | 10° 38# | 15° 48# | |
| | 20° 52# | 25° 64# | 30° 73# | |
| | 35° 85# | 40° 98# | 45° 110# | |
| 100 | 5° 30# | 10° 38# | 15° 46# | |
| | 20° 58# | 25° 65# | 30° 80# | |
| | 35° 95# | 40° 110# | 45° 115# | |
| 110 | 5° 33# | 10° 40# | 15° 48# | |
| | 20° 58# | 25° 65# | 30° 80# | |
| | 35° 98# | 40° 110# | 45° 120# | |
| 120 | 5° 35# | 10° 40# | 15° 50# | |
| | 20° 60# | 25° 68# | 30° 80# | |
| | 35° 98# | 40° 110# | 45° 125# | |
| 130 | 5° 35# | 10° 43# | 15° 54# | |
| | 20° 65# | 25° 75# | 30° 90# | |
| | 35° 105# | 40° 120# | 45° 135# | |
| 140 | 5° 40# | 10° 45# | 15° 55# | |
| | 20° 65# | 25° 70# | 30° 95# | |
| | 35° 115# | 40° 130# | 45° 145# | |
| 150 | 5° 35# | 10° 48# | 15° 62# | |
| | 20° 73# | 25° 88# | 30° 100# | |
| | 35° 115# | 40° 135# | 45° 160# | |

Test Engineer J. Martinez Test Technician [illegible signature]

# DESIGN VERIFICATION TEST

## TEST DATA SHEET

Type of Test: Flexural Resistance Evaluation (Para. 5.2) Date of Test: 9/17/69

Part Name: Flex Hose Assembly P/N 8-030962=3 Test Procedure: 8-480088

| Pressure (PSIG) | Deflection & Force | | | Remarks |
|---|---|---|---|---|
| 10 | 5° 12# | 10° 16# | 15° 20# | |
| | 20° 23# | 25° 25# | 30° 25# | |
| | 35° 25# | 40° 28# | 45° 30# | |
| 20 | 5° 20# | 10° 20# | 15° 20# | |
| | 20° 30# | 25° 30# | 30° 30# | |
| | 35° 32# | 40° 38# | 45° 45# | |
| 30 | 5° 15# | 10° 18# | 15° 20# | |
| | 20° 24# | 25° 28# | 30° 30# | |
| | 35° 30# | 40° 32# | 45° 35# | |
| 40 | 5° 18# | 10° 20# | 15° 20# | |
| | 20° 20# | 25° 25# | 30° 28# | |
| | 35° 32# | 40° 35# | 45° 40# | |
| 50 | 5° 20# | 10° 21# | 15° 24# | |
| | 20° 25# | 25° 28# | 30° 30# | |
| | 35° 32# | 40° 40# | 45° 40# | |
| 60 | 5° 20# | 10° 20# | 15° 23# | |
| | 20° 25# | 25° 30# | 30° 30# | |
| | 35° 35# | 40° 42# | 45° 48# | |
| 70 | 5° 23# | 10° 23# | 15° 25# | |
| | 20° 28# | 25° 30# | 30° 35# | |
| | 35° 38# | 40° 50# | 45° 55# | |

| Pressure (PSIG) | Deflection & Force | | | Remarks |
|---|---|---|---|---|
| 80 | 5° 25# | 10° 25# | 15° 28# | |
| | 20° 30# | 25° 32# | 30° 38# | |
| | 35° 40# | 40° 50# | 45° 60# | |
| 90 | 5° 22# | 10° 25# | 15° 28# | |
| | 20° 30# | 25° 35# | 30° 40# | |
| | 35° 45# | 40° 55# | 45° 60# | |
| 100 | 5° 25# | 10° 28# | 15° 30# | |
| | 20° 32# | 25° 38# | 30° 42# | |
| | 35° 50# | 40° 60# | 45° 62# | |
| 110 | 5° 25# | 10° 28# | 15° 32# | |
| | 20° 35# | 25° 40# | 30° 45# | |
| | 35° 50# | 40° 60# | 45° 65# | |
| 120 | 5° 25# | 10° 30# | 15° 35# | |
| | 20° 38# | 25° 42# | 30° 48# | |
| | 35° 55# | 40° 62# | 45° 70# | |
| 130 | 5° 30# | 10° 32# | 15° 35# | |
| | 20° 40# | 25° 48# | 30° 55# | |
| | 35° 60# | 40° 65# | 45° 70# | |
| 140 | 5° 30# | 10° 32# | 15° 38# | |
| | 20° 40# | 25° 48# | 30° 52# | |
| | 35° 58# | 40° 65# | 45° 72# | |
| 150 | 5° 30# | 10° 35# | 15° 40# | |
| | 20° 45# | 25° 52# | 30° 60# | |
| | 35° 65# | 40° 72# | 45° 80# | |

Test Engineer J. Martinez Test Technician [illegible]

# DESIGN VERIFICATION TEST

## TEST DATA SHEET

Type of Test: Flexural Resistance Evaluation (Para. 5.2) Date of Test: 9/15/69

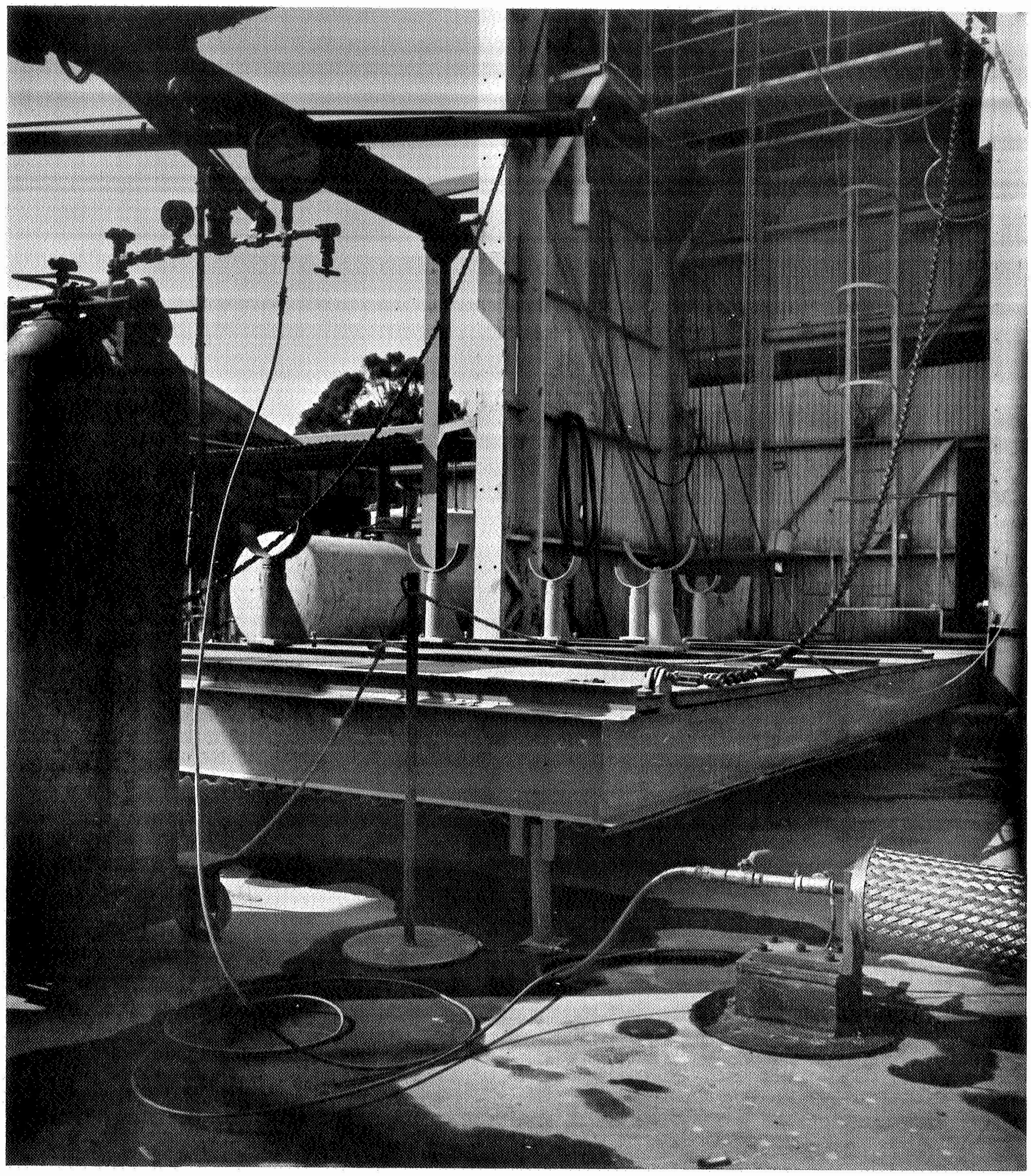
Part Name: Flex Hose Assembly P/N 8-030962-5 Test Procedure: 8-480088

| Pressure (PSIG) | Deflection & Force | | | Remarks |
|---|---|---|---|---|
| 10 | 5° 20# | 10° 30# | 15° 26# | |
| | 20° 35# | 25° 35# | 30° 40# | |
| | 35° 41# | 40° 40# | 45° 50# | |
| 20 | 5° 21# | 10° 30# | 15° 32# | |
| | 20° 39# | 25° 42# | 30° 50# | |
| | 35° 52# | 40° 65# | 45° 66# | |
| 30 | 5° 30# | 10° 41# | 15° 65# | |
| | 20° 66# | 25° 75# | 30° 75# | |
| | 35° 82# | 40° 83# | 45° 90# | |
| 40 | 5° 30# | 10° 35# | 15° 46# | |
| | 20° 53# | 25° 63# | 30° 71# | |
| | 35° 82# | 40° 94# | 45° 110# | |
| 50 | 5° 41# | 10° 51# | 15° 56# | |
| | 20° 62# | 25° 75# | 30° 80# | |
| | 35° 91# | 40° 109# | 45° 124# | |
| 60 | 5° 46# | 10° 62# | 15° 66# | |
| | 20° 70# | 25° 85# | 30° 95# | |
| | 35° 109# | 40° 123# | 45° 139# | |
| 70 | 5° 60# | 10° 65# | 15° 75# | |
| | 20° 84# | 25° 95# | 30° 103# | |
| | 35° 125# | 40° 135# | 45° 152# | |

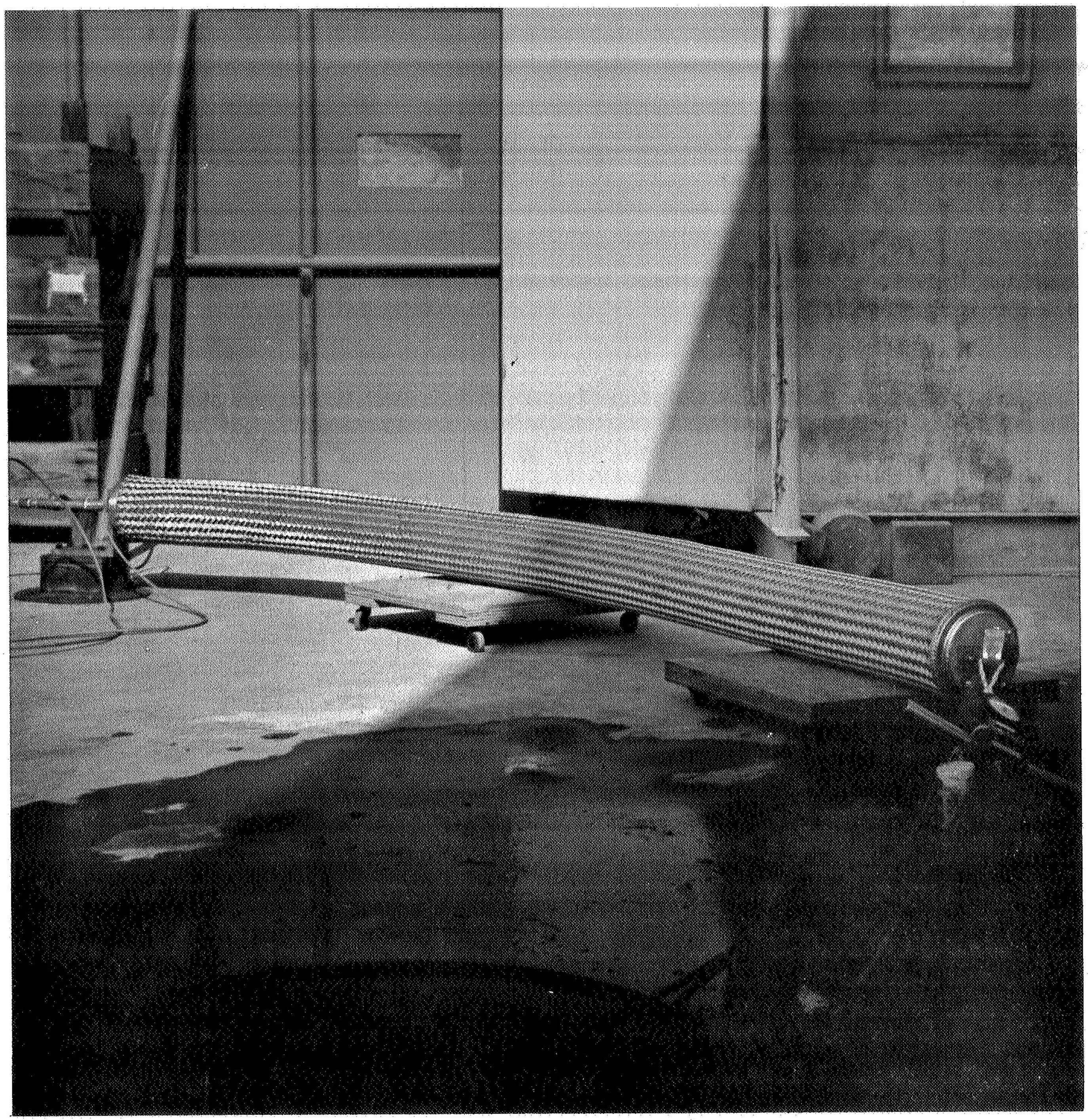
| Pressure (PSIG) | Deflection & Force | | | | | | Remarks |
|---|---|---|---|---|---|---|---|
| 80 | 5° | 64# | 10° | 65# | 15° | 80# | |
| | 20° | 86# | 25° | 105# | 30° | 113# | |
| | 35° | 132# | 40° | 147# | 45° | 165# | |
| 90 | 5° | 70# | 10° | 74# | 15° | 89# | |
| | 20° | 101# | 25° | 110# | 30° | 126# | |
| | 35° | 150# | 40° | 155# | 45° | 175# | |
| 100 | 5° | 75# | 10° | 80# | 15° | 94# | |
| | 20° | 106# | 25° | 122# | 30° | 135# | |
| | 35° | 156# | 40° | 172# | 45° | 180# | |
| 110 | 5° | 80# | 10° | 87# | 15° | 103# | |
| | 20° | 173# | 25° | 132# | 30° | 150# | |
| | 35° | 166# | 40° | 184# | 45° | 209# | |
| 120 | 5° | 83# | 10° | 94# | 15° | 107# | |
| | 20° | 123# | 25° | 138# | 30° | 155# | |
| | 35° | 180# | 40° | 202# | 45° | 222# | |
| 130 | 5° | 86# | 10° | 98# | 15° | 113# | |
| | 20° | 130# | 25° | 146# | 30° | 164# | |
| | 35° | 190# | 40° | 213# | 45° | 238# | |
| 140 | 5° | 95# | 10° | 107# | 15° | 126# | |
| | 20° | 144# | 25° | 162# | 30° | 180# | |
| | 35° | 204# | 40° | 232# | 45° | 256# | |
| 150 | 5° | 108# | 10° | 123# | 15° | 144# | |
| | 20° | 162# | 25° | 177# | 30° | 203# | |
| | 35° | 228# | 40° | 253# | 45° | 277# | |

Test Engineer ____________________ Test Technician ____________________

Pressurized Flex Hose Evaluation Flexure Test Setup
For Angular Deflection



Pressurization Method Showing $GN_2$ Bottles For Pressurized Flex Hose Test



Angulation Of Flex Hose For Pressurized
Load-Deflection Test

3.2.2.3.3 Parallel Offset Deflection Test - Evaluation

Test Requirement

This test was performed to determine the test specimen's resistance to parallel offset deflection while pressurized. Twelve inches of deflection was used.

Test Procedure

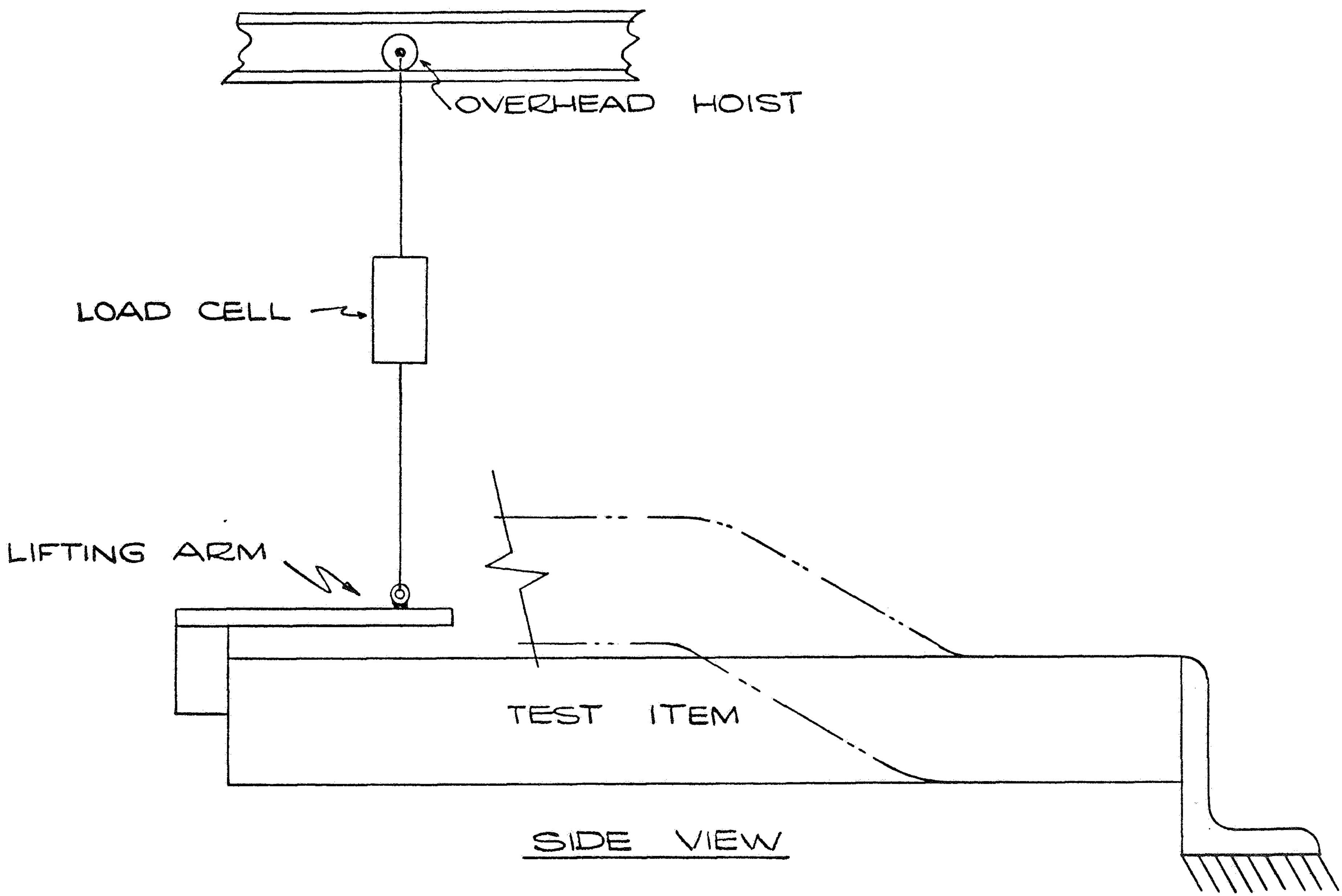
Three test items (-1, -3 and -5 as shown on Page 82) were subjected to this test.

The test item was installed in a test fixture as shown on Page 97 with one end in the fixed position. The test item was pressurized with water in 10 psi increments from 0 to 150 psig. At each 10 psi increment, the test item was deflected through 12 inches of offset deflection in one-inch increments. The force required to restrain the test item at each one-inch of deflection and at each 10 psi increment was recorded.

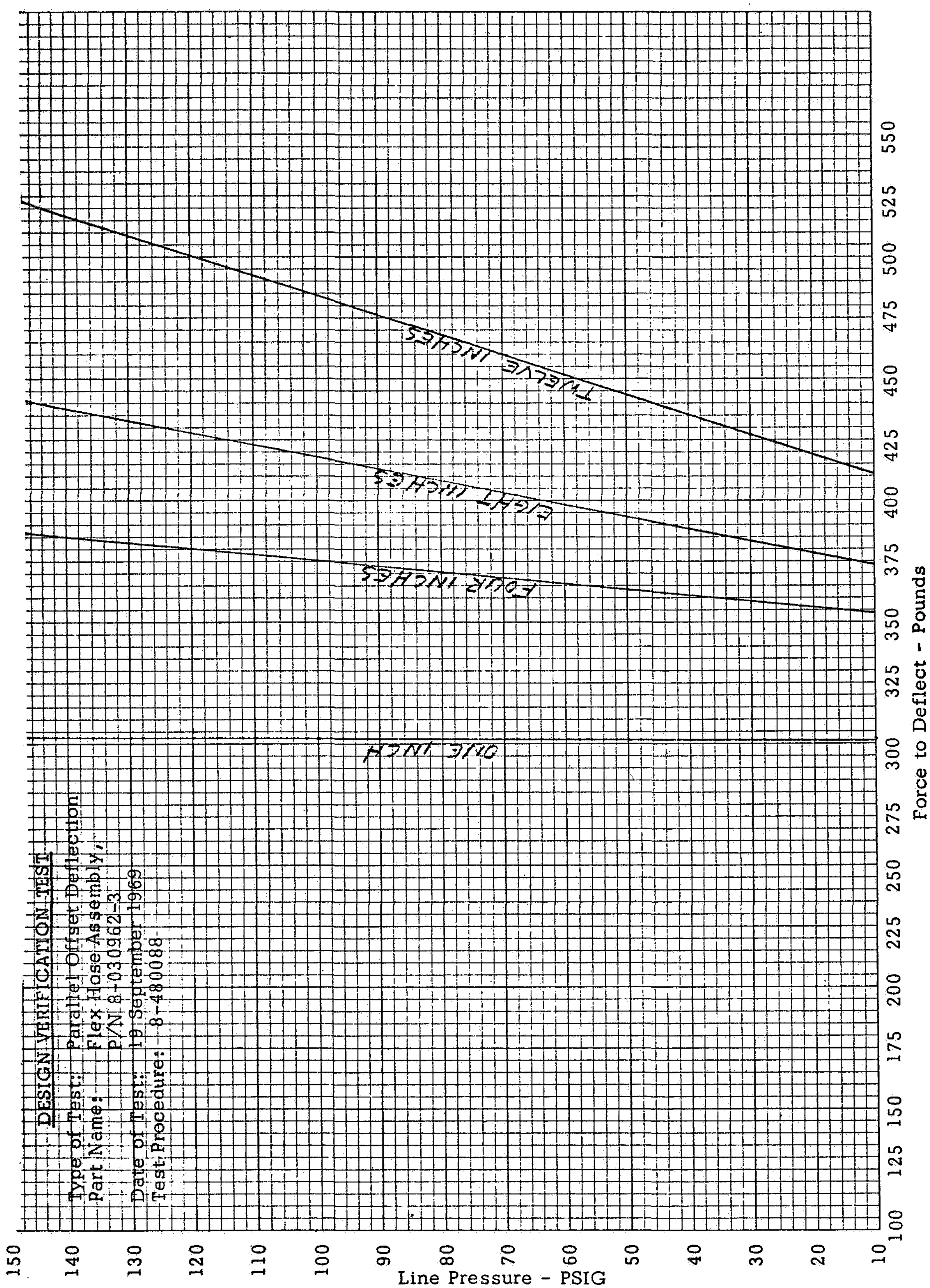
Each increment of deflection (in one-inch increments) was recorded. The force load at each 10 psig increment from 0 to 150 psig was recorded at each one-inch deflection.

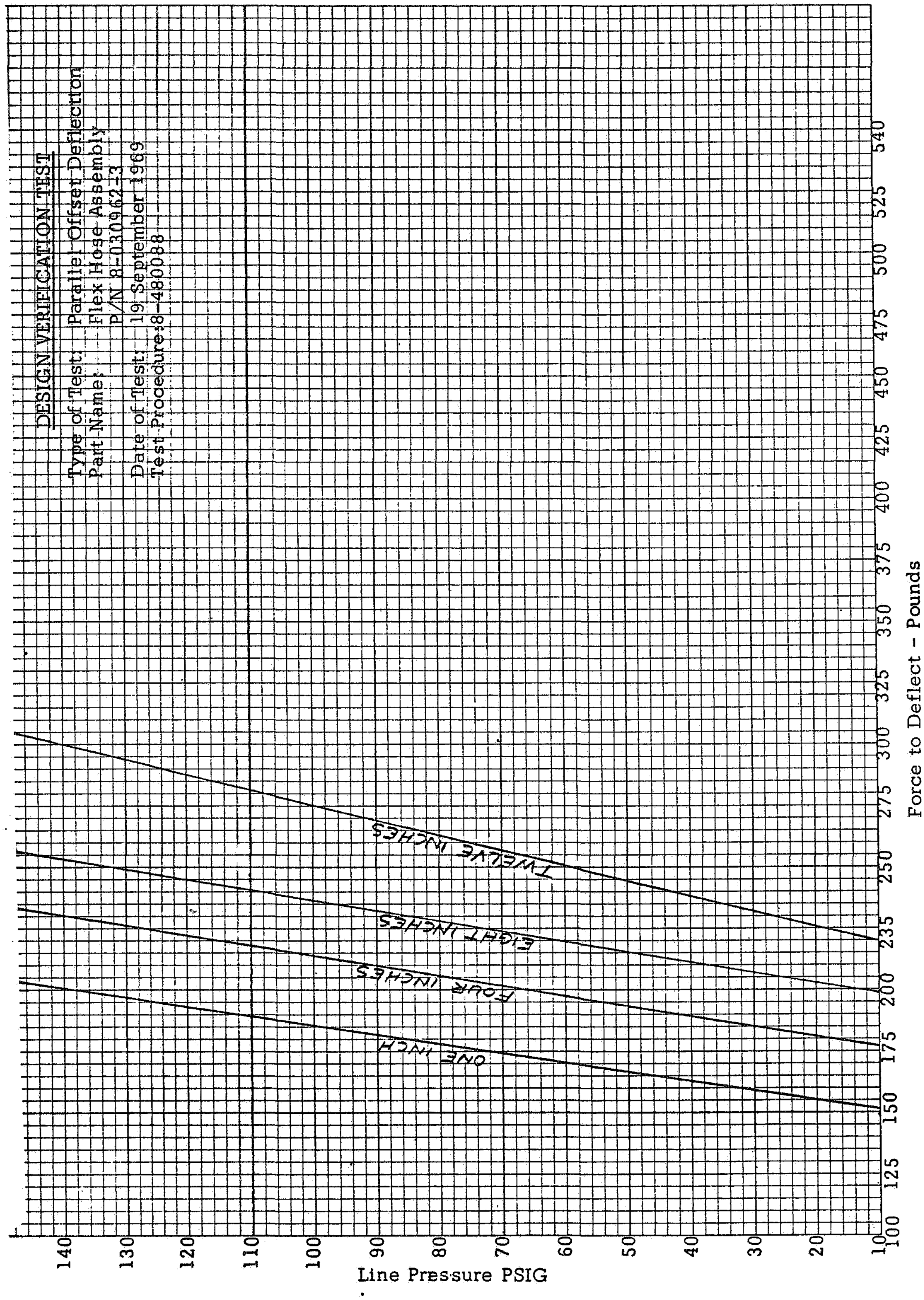
Test Results

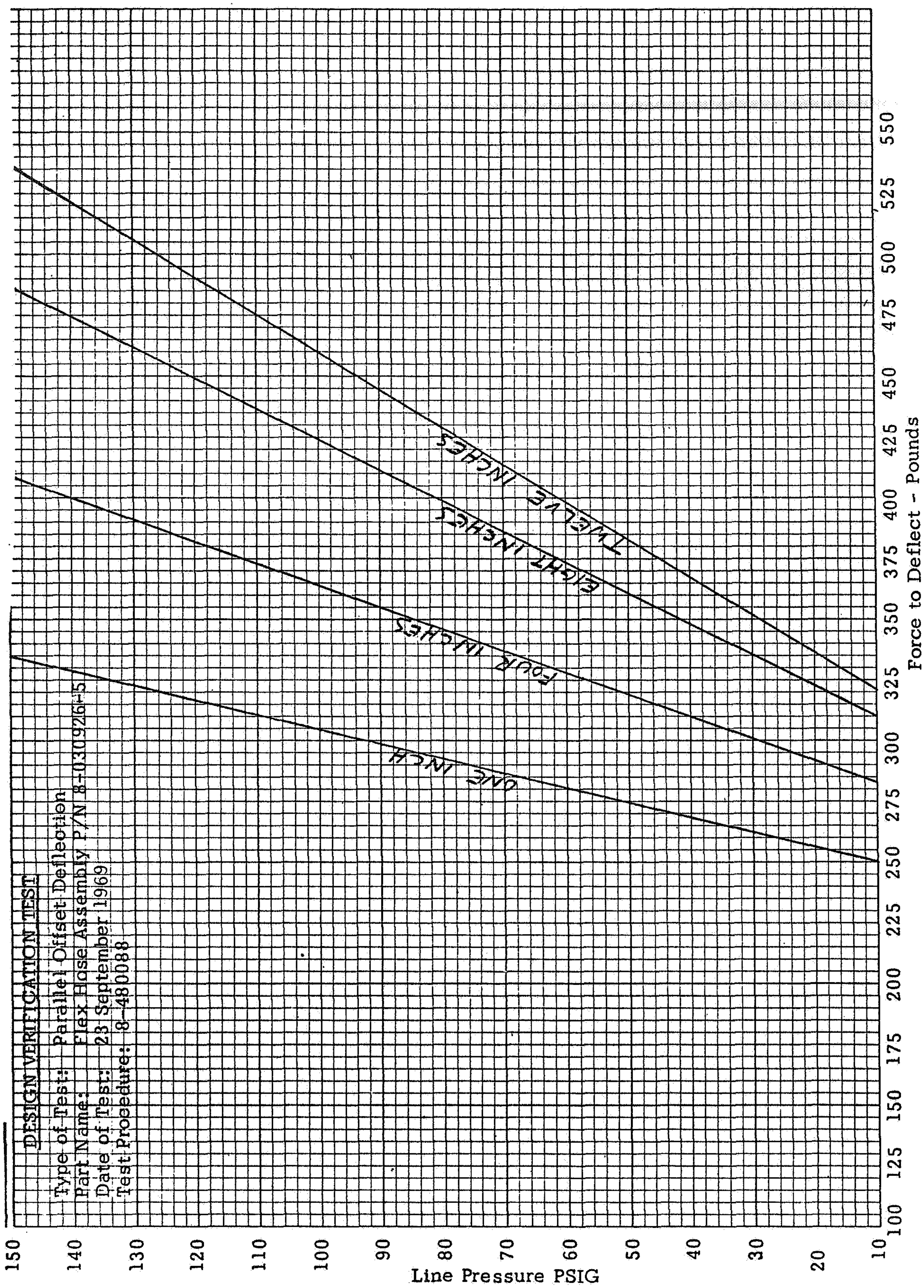
The results of the parallel offset deflection tests, as graphically depicted on the curves which follow, show the erratic nature of loading in parallel offset deflection but it can be seen that the longer (21 feet) more slender (6 inch diameter) hose, P/N 8-030962-3 offered much less resistance to deflection than the shorter hoses. It is interesting to note that at the full 12 inches of deflection, both the 11 feet long hoses produced a load of 525 pounds although one (8-030962-5) is 8 inches diameter and the other (8-030962-1) is 6 inches diameter. The erratic load readings is believed to be the result of braid configuration. When a tubular braided member is offset deflected under load, the braid spreads in some areas and bunches up in some others. It also takes a permanent set at intervals and the wires making up the braid strain harden. Regardless of the foregoing, in general the deflection increases proportionately with the load.




Test Set-Up, Parallel Offset Pressurized Line Flexure


DESIGN VERIFICATION TEST
Type of Test: Parallel Offset Deflection
Part Name: Flex Hose Assembly,
P/N 8-030962-3
Date of Test: 19 September 1969
Test Procedure: 8-480088
TWELVE INCHES
EIGHT INCHES
FOUR INCHES
ONE INCH
100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500 525 550
Force to Deflect - Pounds
150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
Line Pressure - PSIG


DESIGN VERIFICATION TEST
Type of Test: Parallel Offset Deflection
Part Name: Flex Hose Assembly
P/N 8-030962-3
Date of Test: 19 September 1969
Test Procedure: 8-480088
ONE INCH
FOUR INCHES
EIGHT INCHES
TWELVE INCHES
Force to Deflect - Pounds
100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500 525 540
Line Pressure PSIG
140 130 120 110 100 90 80 70 60 50 40 30 20 10


DESIGN VERIFICATION TEST
Type of Test: Parallel Offset Deflection
Part Name: Flex Hose Assembly P/N 8-030926-5
Date of Test: 23 September 1969
Test Procedure: 8-480088
ONE INCH
FOUR INCHES
EIGHT INCHES
TWELVE INCHES
Force to Deflect - Pounds
100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500 525 550
Line Pressure PSIG
150 140 130 120 110 100 90 80 70 60 50 40 30 20 10

## Test Data

The following data sheets give the loads due to parallel offset deflection for each 10 psig increase in pressure and each inch of deflection for the three (3) configurations tested. The photographs which follow the data sheets were taken during testing.

## DESIGN VERIFICATION TEST

## TEST DATA SHEET

Type of Test: Parallel Offset Deflection  Date of Test: 9/24/69

Part Name: Flex Hose Assembly (8-030926-1)  Test Procedure: 8-480088

| Pressure PSIG | Height in Inches / Force in Pounds | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 10 | 302 | 334 | 357 | 372 | 373 | 375 | 379 | 380 | 388 | 396 | 388 | 413 |
| 20 | 301 | 321 | 355 | 350 | 351 | 355 | 361 | 365 | 370 | 389 | 398 | 414 |
| 30 | 303 | 331 | 360 | 350 | 355 | 361 | 369 | 378 | 392 | 397 | 406 | 440 |
| 40 | 299 | 322 | 356 | 352 | 360 | 370 | 376 | 372 | 409 | 417 | 419 | 449 |
| 50 | 294 | 310 | 320 | 340 | 357 | 373 | 380 | 380 | 420 | 420 | 420 | 445 |
| 60 | 301 | 309 | 361 | 355 | 362 | 371 | 391 | 391 | 464 | 479 | 480 | 449 |
| 70 | 296 | 315 | 340 | 373 | 380 | 413 | 460 | 467 | 476 | 484 | 484 | 484 |
| 80 | 304 | 341 | 351 | 379 | 391 | 379 | 451 | 444 | 446 | 450 | 470 | 470 |
| 90 | 320 | 357 | 388 | 405 | 405 | 380 | 430 | 430 | 452 | 452 | 460 | 450 |
| 100 | 299 | 351 | 361 | 385 | 390 | 390 | 425 | 448 | 461 | 471 | 475 | 488 |
| 110 | 298 | 358 | 365 | 380 | 380 | 396 | 420 | 450 | 468 | 485 | 485 | 492 |
| 120 | 303 | 352 | 360 | 380 | 389 | 385 | 420 | 450 | 460 | 480 | 491 | 506 |
| 130 | 301 | 355 | 352 | 379 | 388 | 390 | 420 | 450 | 465 | 485 | 495 | 511 |
| 140 | 298 | 355 | 350 | 385 | 401 | 403 | 425 | 440 | 462 | 489 | 506 | 518 |
| 150 | 300 | 355 | 351 | 381 | 405 | 410 | 412 | 431 | 462 | 489 | 509 | 525 |

REMARKS:

Test Technician  Test Engineer

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Parallel Offset Deflection Date of Test 9/19/69

Part Name Flex Hose Assembly P/N 8-030962-3 Test Procedure 8-480088

| Pressure PSIG | Height in Inches / Force in Pounds | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 10 | 150 | 171 | 176 | 179 | 182 | 184 | 200 | 200 | 203 | 204 | 205 | 210 |
| 20 | 151 | 171 | 176 | 179 | 183 | 189 | 206 | 210 | 216 | 211 | 231 | 235 |
| 30 | 160 | 178 | 179 | 180 | 190 | 191 | 210 | 215 | 219 | 226 | 230 | 239 |
| 40 | 169 | 185 | 180 | 194 | 201 | 210 | 218 | 221 | 231 | 231 | 239 | 240 |
| 50 | 180 | 180 | 181 | 195 | 208 | 220 | 223 | 224 | 224 | 235 | 240 | 245 |
| 60 | 180 | 182 | 181 | 195 | 208 | 220 | 220 | 223 | 226 | 236 | 242 | 260 |
| 70 | 186 | 187 | 190 | 195 | 211 | 221 | 221 | 226 | 229 | 235 | 249 | 269 |
| 80 | 190 | 196 | 198 | 208 | 214 | 219 | 220 | 223 | 233 | 239 | 252 | 271 |
| 90 | 191 | 200 | 206 | 210 | 215 | 216 | 220 | 223 | 234 | 240 | 256 | 272 |
| 100 | 190 | 201 | 208 | 211 | 220 | 222 | 230 | 229 | 250 | 261 | 269 | 281 |
| 110 | 189 | 205 | 211 | 219 | 226 | 229 | 231 | 240 | 277 | 262 | 275 | 284 |
| 120 | 190 | 205 | 215 | 222 | 228 | 230 | 235 | 263 | 280 | 280 | 300 | 301 |
| 130 | 192 | 208 | 218 | 222 | 227 | 230 | 238 | 248 | 275 | 279 | 281 | 300 |
| 140 | 201 | 213 | 220 | 224 | 229 | 235 | 240 | 250 | 278 | 280 | 286 | 302 |
| 150 | 205 | 215 | 222 | 225 | 230 | 235 | 245 | 250 | 260 | 275 | 286 | 300 |

REMARKS:

Test Technician Test Engineer

DESIGN VERIFICATION TEST

TEST DATA SHEET

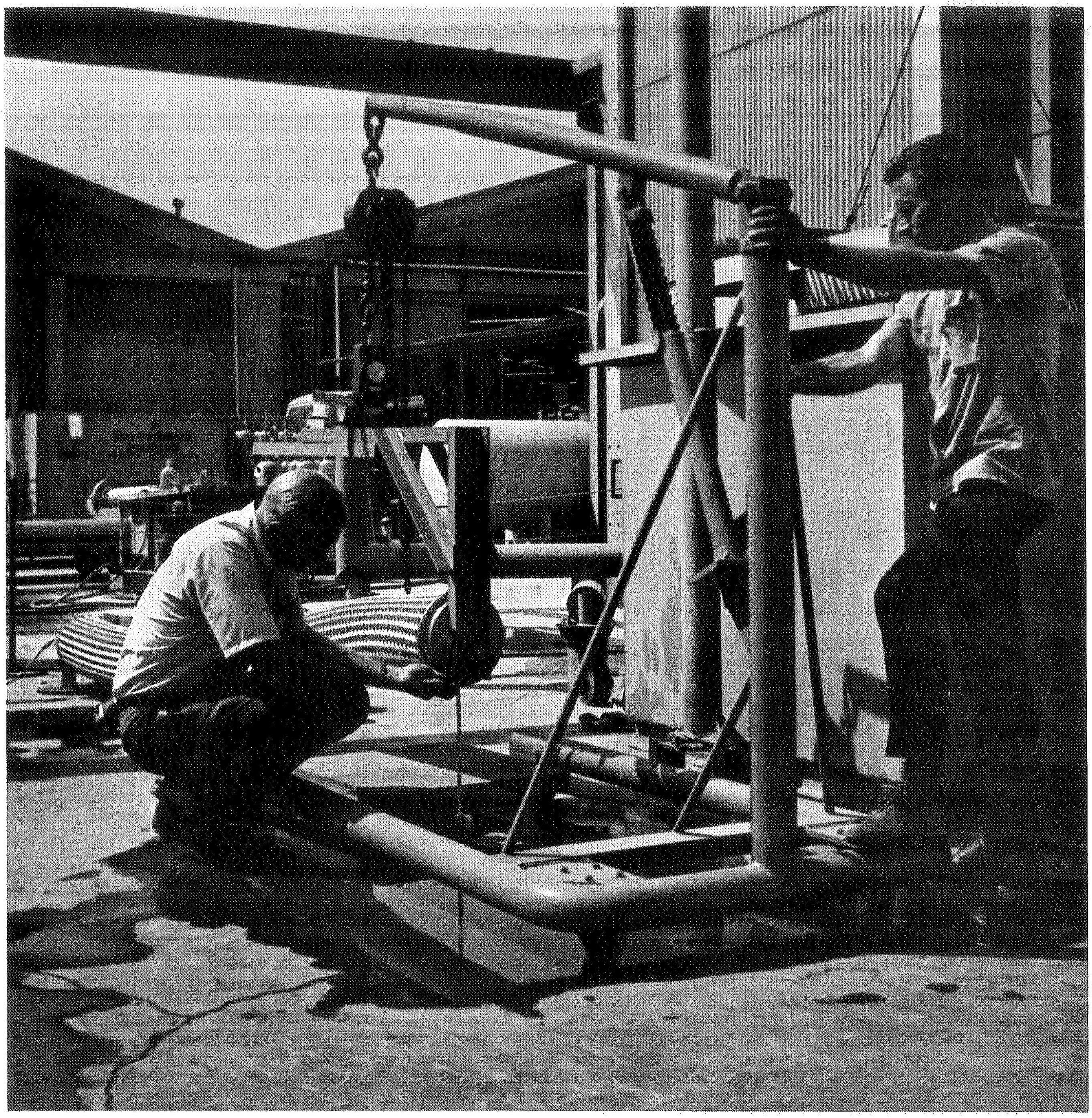
Type of Test Parallel Offset Deflection Date of Test 9/23/69

Part Name Flex Hose Assembly P/N 8-030926-5 Test Procedure 8-480088

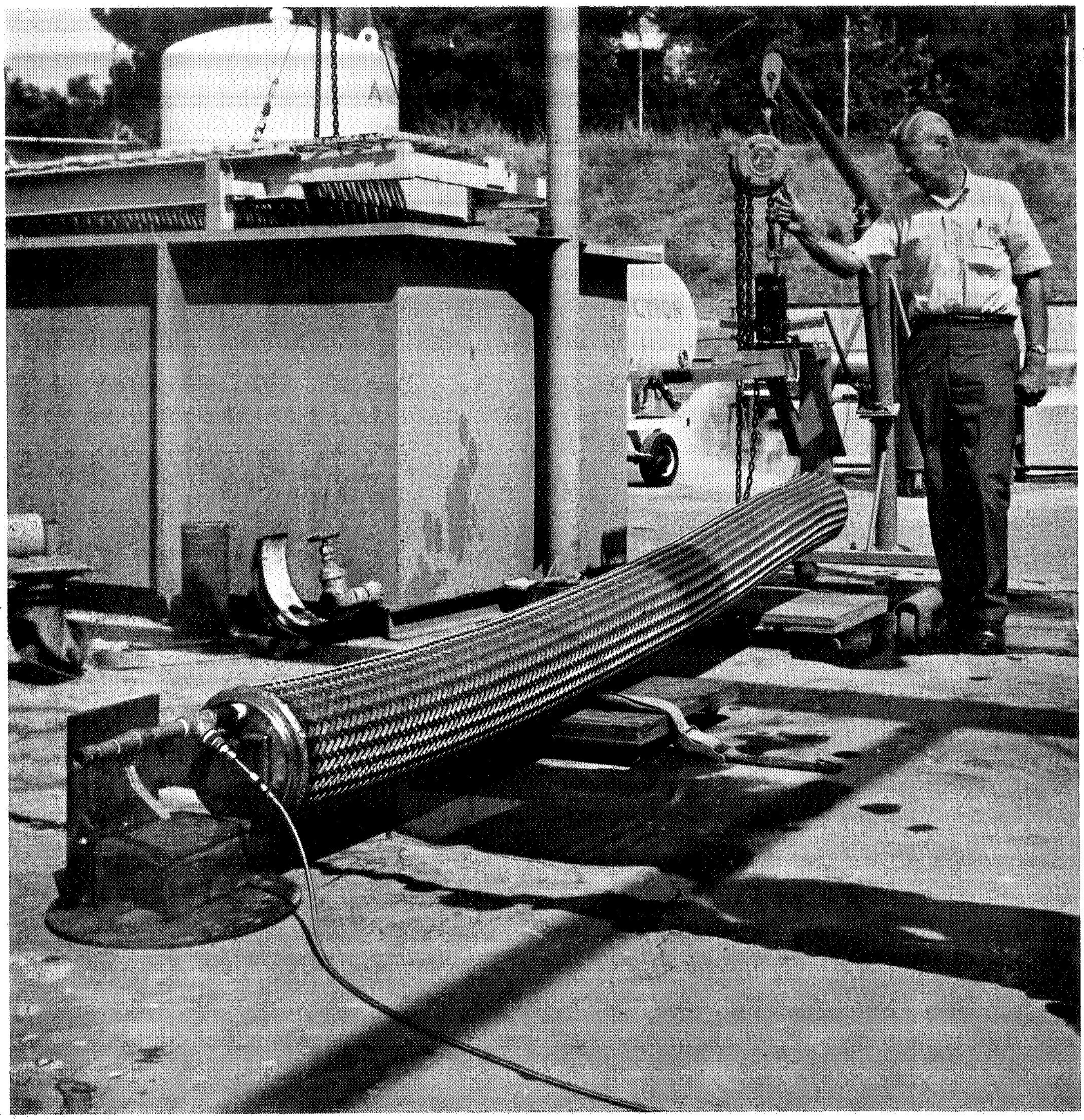
| Pressure PSIG | Height in Inches / Force in Pounds | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | **12** |
| 10 | 250 | 272 | 279 | 283 | 290 | 294 | 290 | 308 | 309 | 315 | 320 | **323** |
| 20 | 250 | 270 | 281 | 286 | 301 | 311 | 316 | 331 | 330 | 329 | 333 | **330** |
| 30 | 258 | 290 | 296 | 301 | 316 | 331 | 326 | 362 | 371 | 380 | 381 | **389** |
| 40 | 278 | 301 | 309 | 321 | 331 | 347 | 360 | 377 | 380 | 385 | 389 | **395** |
| 50 | 283 | 308 | 325 | 335 | 341 | 360 | 381 | 389 | 390 | 392 | 402 | **405** |
| 60 | 291 | 335 | 331 | 369 | 362 | 372 | 382 | 380 | 388 | 391 | 399 | **399** |
| 70 | 308 | 345 | 350 | 370 | 377 | 382 | 385 | 385 | 388 | 391 | 391 | **391** |
| 80 | 311 | 358 | 362 | 381 | 381 | 401 | 409 | 421 | 432 | 450 | 461 | **475** |
| 90 | 352* | 368 | 380 | 393 | 398 | 410 | 457 | 457 | 457 | 476 | 479 | **480** |
| 100 | 312 | 361 | 381 | 396 | 411 | 412 | 451 | 437 | 440 | 471 | 481 | **482** |
| 110 | 310 | 350 | 384 | 400 | 425 | 425 | 434 | 436 | 440 | 467 | 485 | **483** |
| 120 | 313 | 354 | 380 | 401 | 410 | 426 | 456 | 441 | 462 | 471 | 481 | **489** |
| 130 | 321 | 356 | 387 | 390 | 416 | 431 | 461 | 462 | 471 | 480 | 491 | **505** |
| 140 | 330 | 362 | 383 | 406 | 416 | 442 | 465 | 470 | 479 | 491 | 501 | **520** |
| 150 | 332 | 358 | 384 | 400 | 417 | 450 | 467 | 490 | 483 | 500 | 517 | **525** |

REMARKS: *Line braid had taken permanent set, straightened manually to a more normal appearing condition

Test Technician [signature] Test Engineer Ken Kirk



Pressurized Flex Hose Parallel Offset Load Test Setup



Pressurized Flex Hose Parallel Offset Load Test Setup

3.2.2.3.4 Ruggedness Test

Test Requirement

This test was performed to evaluate the resistance of the test item to external damage with various shock absorber materials installed.

The test item was installed in a test fixture as shown on Page 108. The test items for this test were the outer jacket bellows of the basic test item SK4058-1 as modified per SK4058-3, SK4058-4 and SK 4058-5. The tests were conducted in that sequence. A bellows with no protective device was used to establish the force used in testing the modified bellows assemblies. When the force necessary to cause approximately 1/8 inch indentations in the convolutions was reached with consistent repeatability that force was recorded for a $90^{\circ}$ angled blow and a $60^{\circ}$ angled blow, this angle being taken from the longitudinal centerline of the bellows.

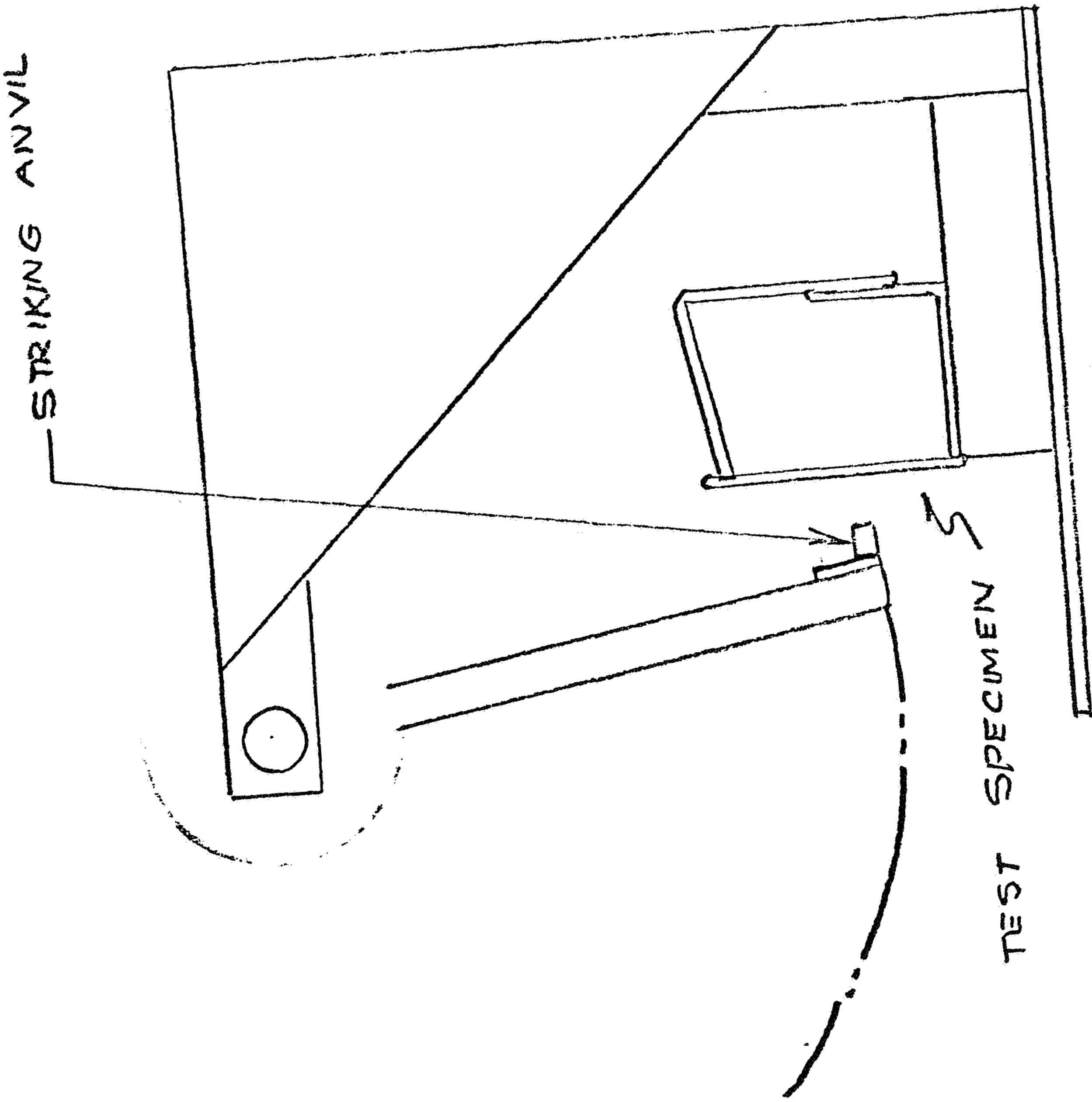
Using these forces for each angle, each of the remaining test items was tested by striking ten blows at each angle. The force required to cause approximately 1/8 inch indentations in the convolutions of the first test item (SK 4058-1) for each($90^{\circ}$ and $60^{\circ}$) angle was recorded.

The depth of the indentations, the striking angle, the force applied, and the number of blows struck were recorded for each of the test items with shock absorber material installed according to the design sketches. The results of each blow on these test items was photographed.

Test Results

The following is a summary of the average indentation made by the testing machine on the various configurations tested starting with the basic braided bellows without protective devices installed.

| Part Number | Description | Striking Angle | Impact Force | Dent Depth |
|---|---|---|---|---|
| SK4058-1 | Basic Braided Bellows | $90^{\circ}$ | 265 lbs | .125" |
| SK4058-1 | Basic Braided Bellows | $60^{\circ}$ | 230 lbs | .125" |
| SK4058-3 | RTV-Cured in place | $90^{\circ}$ | 265 lbs | .055" |
| SK4058-3 | RTV-Cured in place | $60^{\circ}$ | 230 lbs | .087" |
| SK4058-4 | Silicone Bumper Strip | $90^{\circ}$ | 265 lbs | .049" |
| SK4058-4 | Silicone Bumper Strip | $60^{\circ}$ | 230 lbs | .078" |




Test Set-Up, Ruggedness

| Part No. | Description | Striking Angle | Impact Force | Dent Depth |
|---|---|---|---|---|
| SK4058-5 | Nylon Bumper Strip | $90^{\circ}$ | 265 lbs | .071" |
| SK4058-5 | Nylon Bumper Strip | $60^{\circ}$ | 230 lbs | .083" |
| SK4058-5 | Teflon Bumper Strip | $90^{\circ}$ | 265 lbs | .078" |
| SK4058-5 | Teflon Bumper Strip | $60^{\circ}$ | 230 lbs | .095" |

As can be seen from the above compilation, the Silicone Rubber Bumper Strip(SK4058-4) afforded the best protection against a blow struck at $90^{\circ}$ to the longitudinal centerline of the line assembly. Also, the Silicone Bumper Strip performed best when struck with the $60^{\circ}$ angle glancing blow. One significant advantage of the clear RTV Silicone Rubber (SK4058-3) was that the metal area damaged by the blow was visible for inspection purposes. There was little or no tendency for the molded in place (SK4058-3) RTV to peel off or detach when struck; it apparently has good adhesive characteristics in this application. Looking ahead to repairability, these last two observations indicate significant advantages.

The Nylon, Teflon and Molded Silicone Rubber Bumper Strips presented some problems in attachment to the bellows. Several methods were tried (wiring, adhesives, heat sealing and clamping) but none was really satisfactory as all three types of bumper strips showed a tendency to come apart at the circumferential attachment point when the braid was removed. It may be noted here that the $30^{\circ}$ angle strike which was originally proposed in the 8-480088 test procedure document was omitted. Several attempts were made at using this striking angle, but the inconsistency of indentation depth ruled it out as any meaningful data possibility. The sliding tendency of the striking face at the $30^{\circ}$ angle seemed to vary greatly and therefore account for the problem.

Test Data

The following data sheets document the complete set of ten blows struck on each protective device at the $90^{\circ}$ and $60^{\circ}$ angles. It should be noted that the average is given under the remarks column. The photographs which follow the data sheets show test machine calibration and a sampling of tested bellows after the braid and protective devices had been removed to expose the actual line damage. The specimen angles referred to are the angles of the bellows longitudinal centerline relative to the direction from which the blow is struck. The arm angle refers to the height the arm was raised before release. This arm angle corresponds to impact force as $80^{\circ} = 265$ lbs and $70^{\circ} = 230$ lbs.

## DESIGN VERIFICATION TEST

## TEST DATA SHEET

Type of Test Ruggedness Date of Test 23 July 1969

Part Name Bellows SK4058-3 Test Procedure 8-480088

Protective Material RTV Silicone - Cured in Place

| Strike No. | Angle | Force | Depth | Remarks |
|---|---|---|---|---|
| 1 | $90^{\circ}$ | 265 lb. | .059 | |
| 2 | " | " | .065 | |
| 3 | " | " | .042 | |
| 4 | " | " | .035 | |
| 5 | " | " | .068 | |
| 6 | " | " | .058 | |
| 7 | " | " | .060 | |
| 8 | " | " | .070 | |
| 9 | " | " | .040 | |
| 10 | " | " | .058 | .0555 average |
| | | | | |
| | | | | |

Test Technician /s/ L. Mc Knight Test Engineer /s/ K. Kimble

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Ruggedness Date of Test 23 July 1969

Part Name Bellows SK4058-3 Test Procedure 8-480088

Protective Material RTV Silicone - Cured in place

| Strike No. | Angle | Force | Depth | Remarks |
|---|---|---|---|---|
| 1 | 60° | 230 lb. | .080 | |
| 2 | " | " | .090 | |
| 3 | " | " | .100 | |
| 4 | " | " | .080 | |
| 5 | " | " | .075 | |
| 6 | " | " | .088 | |
| 7 | " | " | .070 | |
| 8 | " | " | .080 | |
| 9 | " | " | .085 | |
| 10 | " | " | .125 | .0873 average |
| | | | | |
| | | | | |

Test Technician /s/ L. Mc Knight Test Engineer /s/ K. Kimble

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Ruggedness  Date of Test 23 July 1969

Part Name Bellows SK4058-4  Test Procedure 8-480088

Protective Material Molded Silicone Rubber Strips

| Strike No. | Angle | Force | Depth | Remarks |
|---|---|---|---|---|
| 1 | $90^{\circ}$ | 265 lb | .062 | |
| 2 | " | " | .052 | |
| 3 | " | " | .032 | |
| 4 | " | " | .040 | |
| 5 | " | " | .058 | |
| 6 | " | " | .030 | |
| 7 | " | " | .078 | |
| 8 | " | " | .045 | |
| 9 | " | " | .050 | |
| 10 | " | " | .048 | .0495 average |
| | | | | |
| | | | | |

Test Technician /s/ L. Mc Knight  Test Engineer /s/ K. Kimble

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Ruggedness Date of Test 23 July 1969

Part Name Bellows SK4058-4 Test Procedure 8-480088

Protective Material Molded Silicone Rubber Strips

| Strike No. | Angle | Force | Depth | Remarks |
|---|---|---|---|---|
| 1 | $60^{\circ}$ | 230 lb | .065 | |
| 2 | " | " | .065 | |
| 3 | " | " | .068 | |
| 4 | " | " | .095 | |
| 5 | " | " | .068 | |
| 6 | " | " | .094 | |
| 7 | " | " | .092 | |
| 8 | " | " | .080 | |
| 9 | " | " | .078 | |
| 10 | " | " | .075 | .078 Average |
| | | | | |
| | | | | |

Test Technician /s/ L. Mc Knight Test Engineer /s/ K. Kimble

## DESIGN VERIFICATION TEST

## TEST DATA SHEET

Type of Test Ruggedness Date of Test 23 July 1969

Part Name Bellows Test Procedure 8-480088

Protective Material

| Strike No. | Angle | Force | Depth | Remarks |
|---|---|---|---|---|
| 1 | 90° | 265 lb | .070 | |
| 2 | " | " | .094 | |
| 3 | " | " | .094 | |
| 4 | " | " | .068 | |
| 5 | " | " | .058 | |
| 6 | " | " | .062 | |
| 7 | " | " | .072 | |
| 8 | " | " | .062 | |
| 9 | " | " | .058 | |
| 10 | " | " | .070 | .071 Average |
| | | | | |
| | | | | |

Test Technician /s/ L. Mc Knight Test Engineer /s/ K. Kimble

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Ruggedness Date of Test 23 July 1969

Part Name Bellows SK4058-5 Test Procedure 8-480088

Protective Material Nylon

| Strike No. | Angle | Force | Depth | Remarks |
|---|---|---|---|---|
| 1 | 60° | 230 lb | .042 | |
| 2 | " | " | .062 | |
| 3 | " | " | .094 | |
| 4 | " | " | .094 | |
| 5 | " | " | .068 | |
| 6 | " | " | .100 | |
| 7 | " | " | .095 | |
| 8 | " | " | .083 | |
| 9 | " | " | .089 | |
| 10 | " | " | .105 | .083 average |
| | | | | |
| | | | | |

Test Technician /s/ L. Mc Knight Test Engineer /s/ K. Kimble

## DESIGN VERIFICATION TEST

## TEST DATA SHEET

Type of Test Ruggedness Date of Test 23 July 1969

Part Name Bellows SK4058-5 Test Procedure 8-480088

Protective Material Teflon

| Strike No. | Angle | Force | Depth | Remarks |
|---|---|---|---|---|
| 1 | $90^{\circ}$ | 265 lb | .072 | |
| 2 | " | " | .094 | |
| 3 | " | " | .094 | |
| 4 | " | " | .062 | |
| 5 | " | " | .062 | |
| 6 | " | " | .063 | |
| 7 | " | " | .090 | |
| 8 | " | " | .070 | |
| 9 | " | " | .084 | |
| 10 | " | " | .090 | .078 Average |
| | | | | |
| | | | | |

Test Technician /s/ L. Mc Knight Test Engineer /s/ K. Kimble

DESIGN VERIFICATION TEST

TEST DATA SHEET

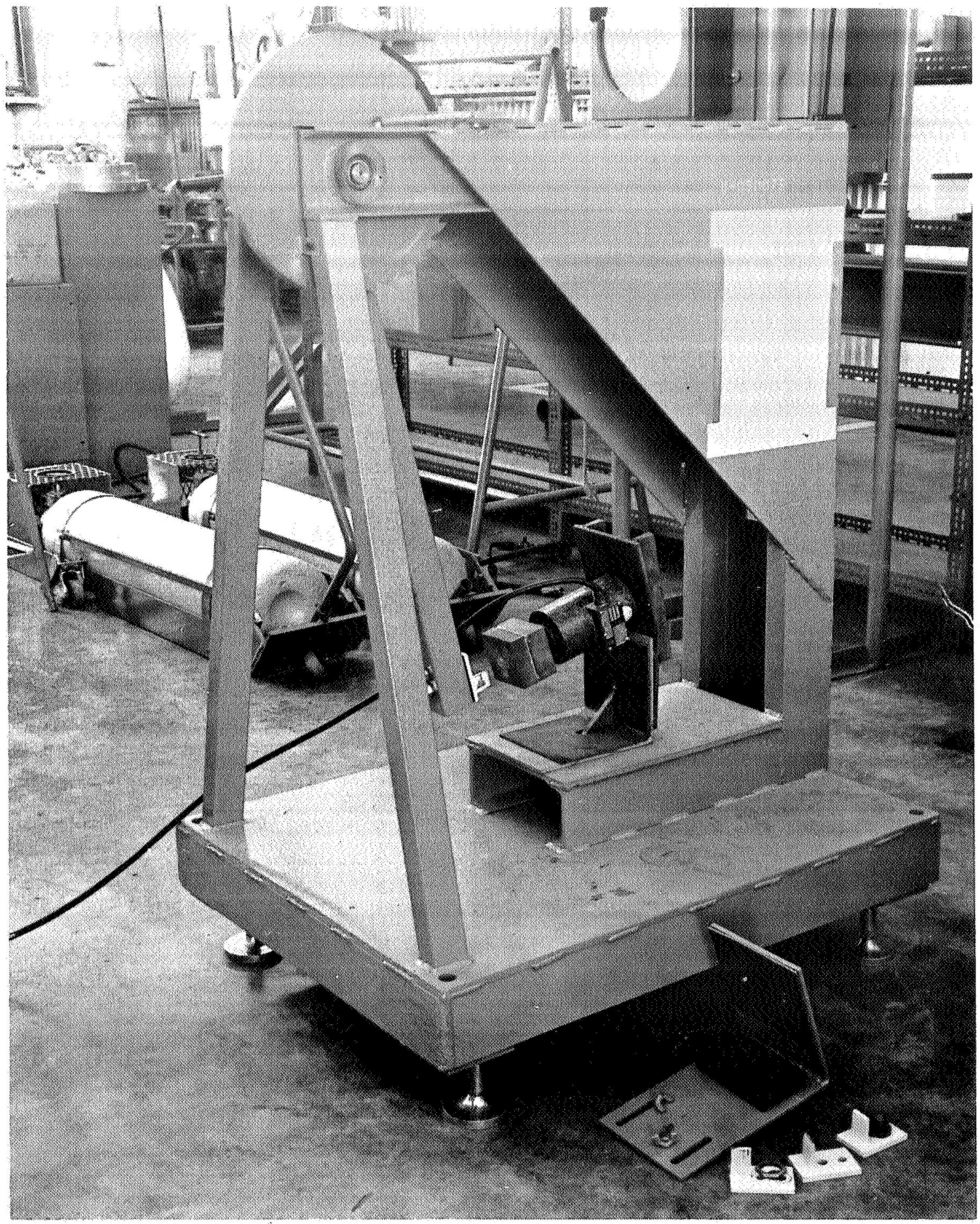
Type of Test Ruggedness Date of Test 23 July 1969

Part Name Bellows SK4058-5 Test Procedure 8-480088

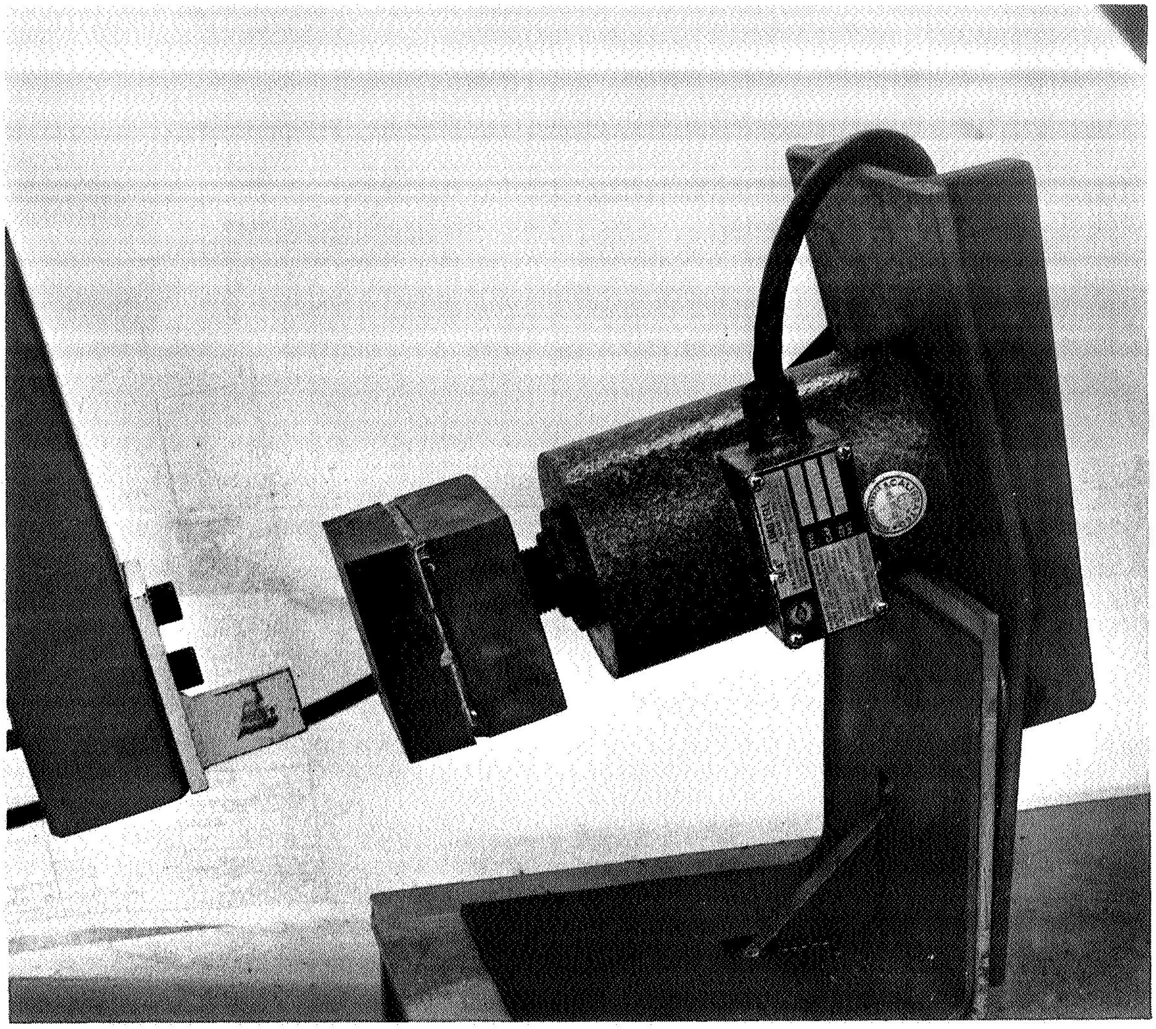
Protective Material Teflon

| Strike No. | Angle | Force | Depth | Remarks |
|---|---|---|---|---|
| 1 | $60^{\circ}$ | 230 lb | .094 | |
| 2 | " | " | .089 | |
| 3 | " | " | .092 | |
| 4 | " | " | .098 | |
| 5 | " | " | .089 | |
| 6 | " | " | .100 | |
| 7 | " | " | .092 | |
| 8 | " | " | .089 | |
| 9 | " | " | .125 | |
| 10 | " | " | .088 | .095 average |
| | | | | |
| | | | | |

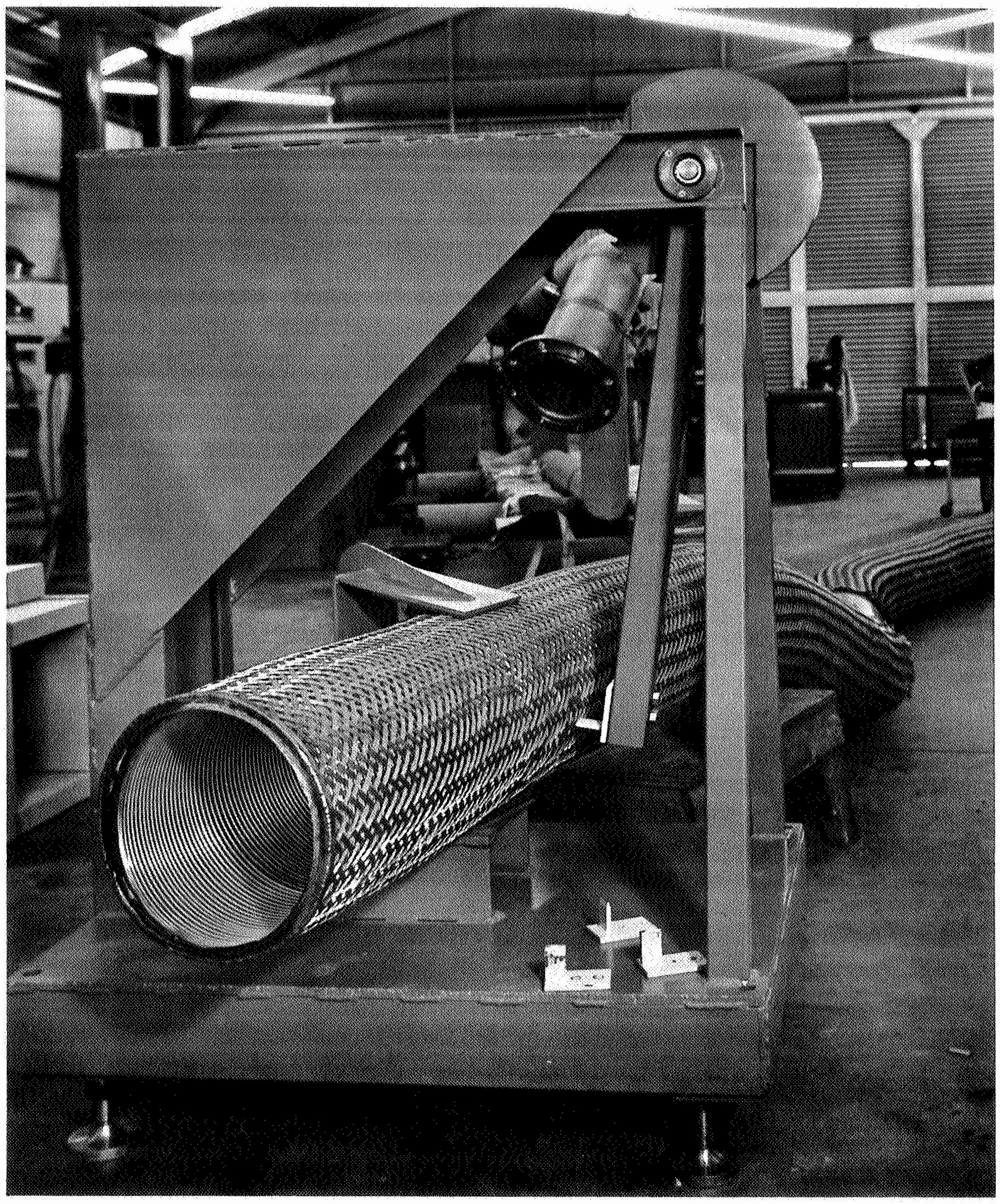
Test Technician /s/ L. Mc Knight Test Engineer /s/ K. Kimble



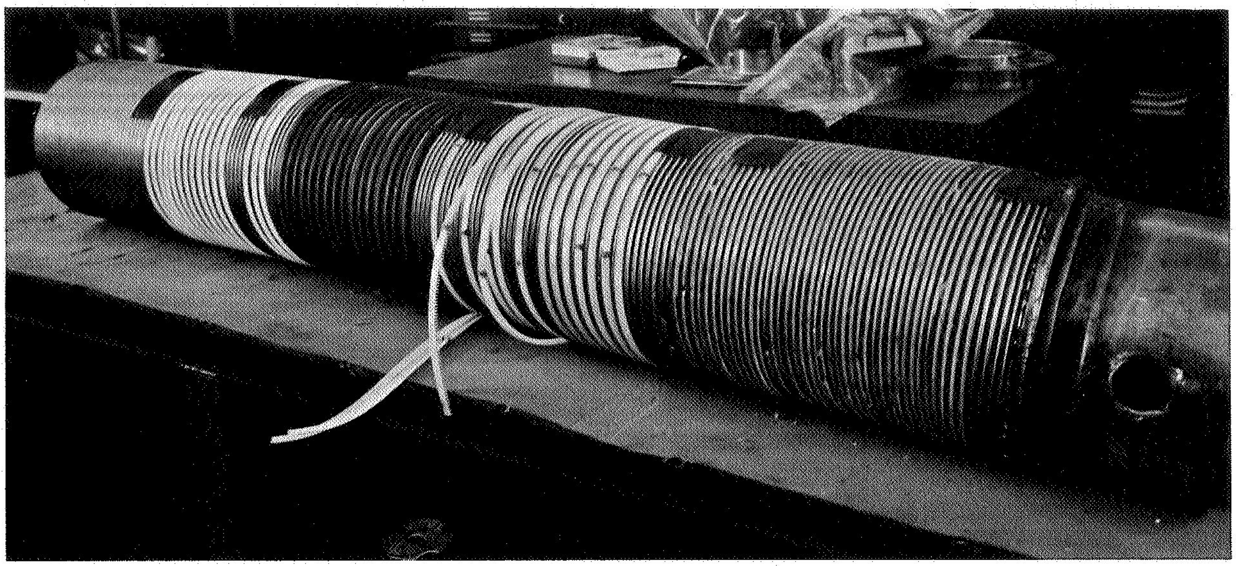
Calibration Of Ruggedness Test Machine Using Load Cell To Measure Force Of Impact



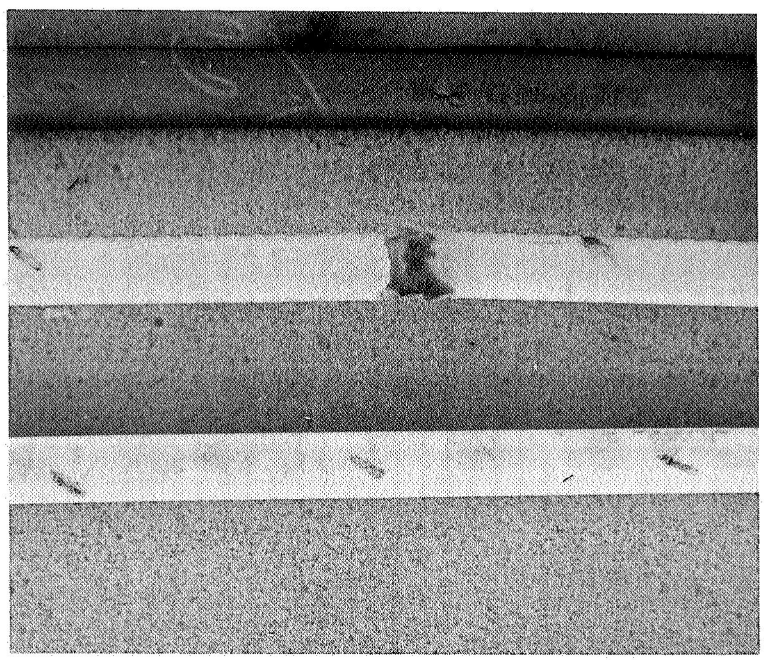
Calibration Of Ruggedness Test Machine Using Load Cell To Measure Force Of Impact



Braided Flexible Hose Installed for Impact
Resistance Testing



Bellows Test Specimen
After Ruggedness Test



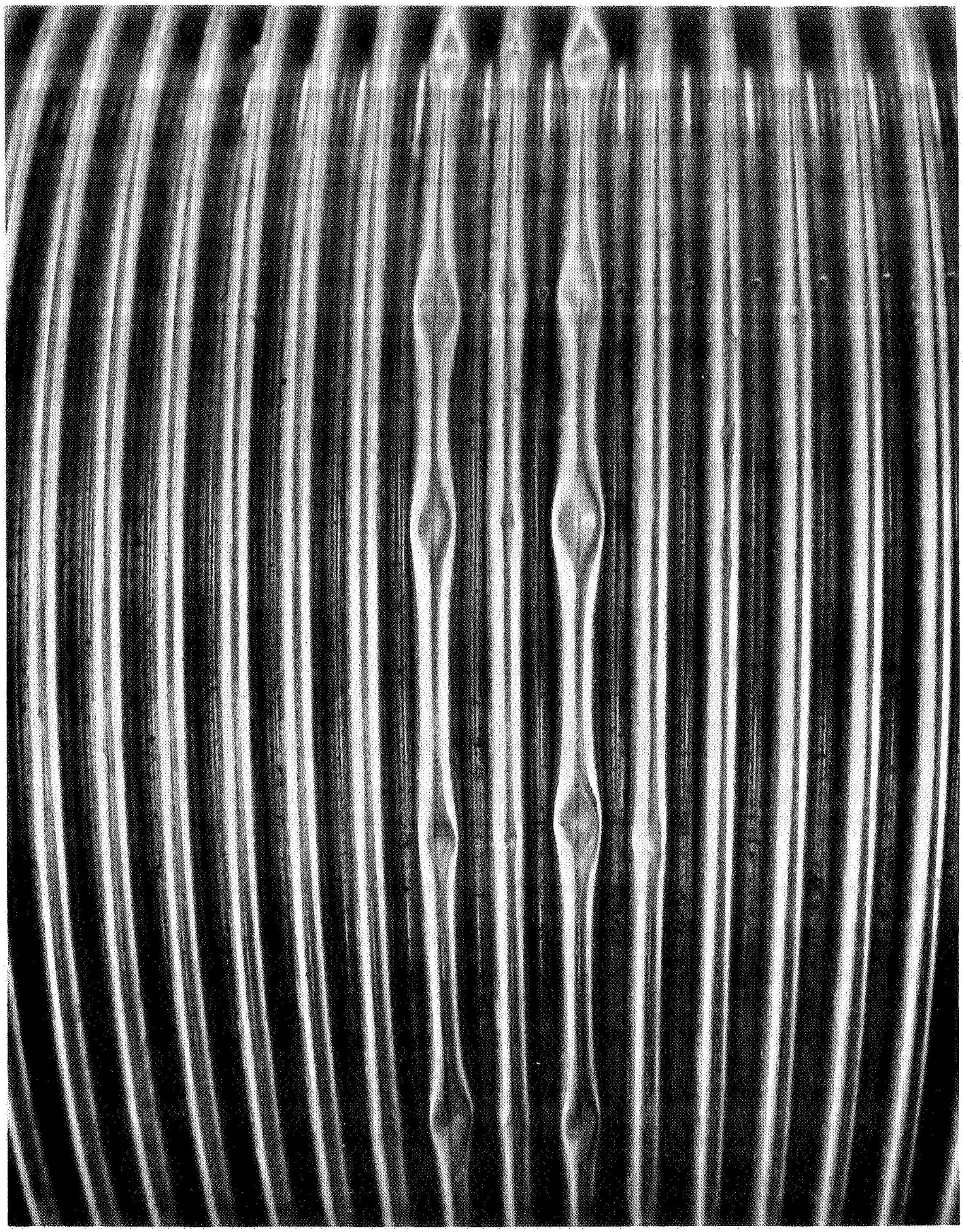
Rubber

Nylon

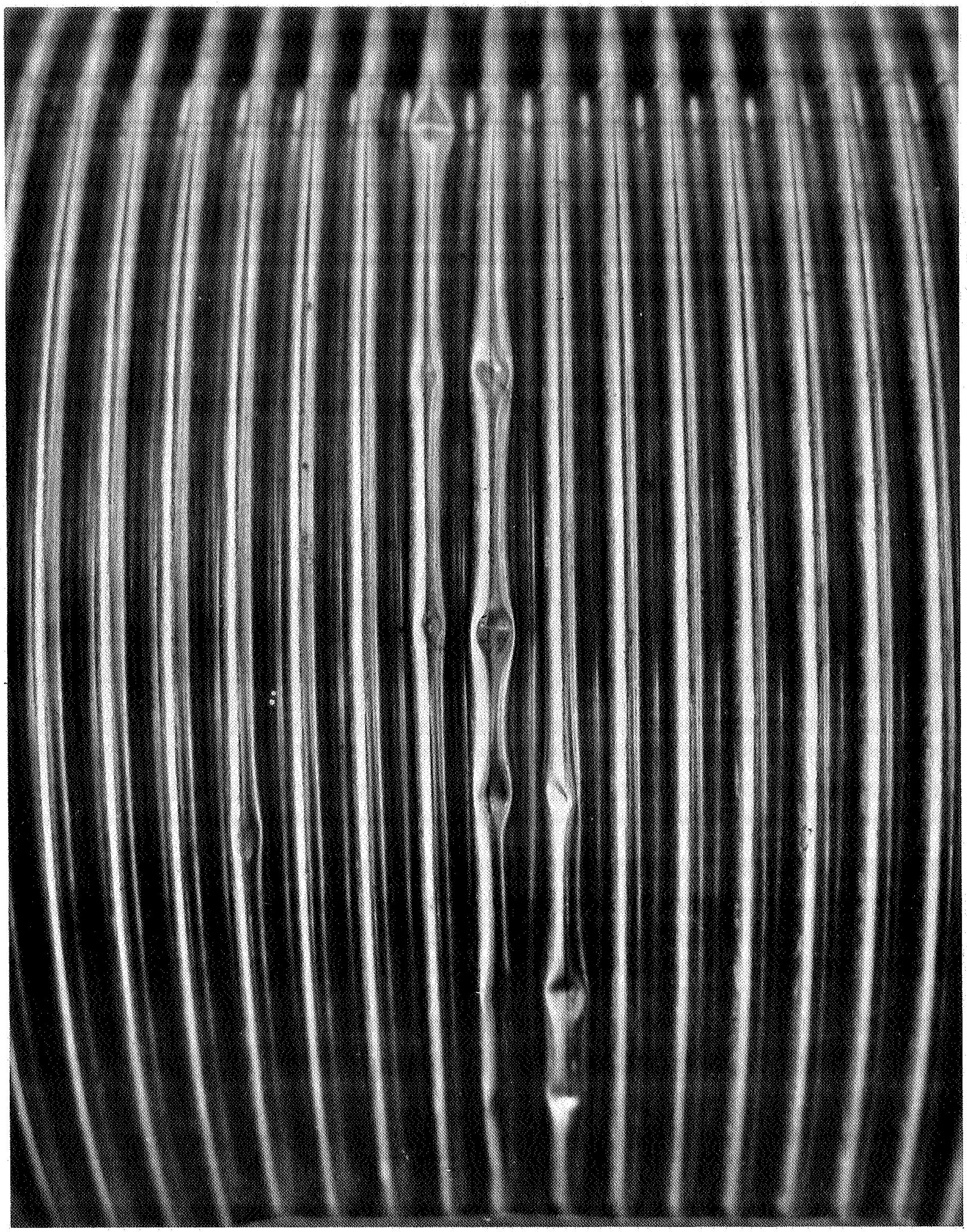
Teflon

Protective Device Material After Damage

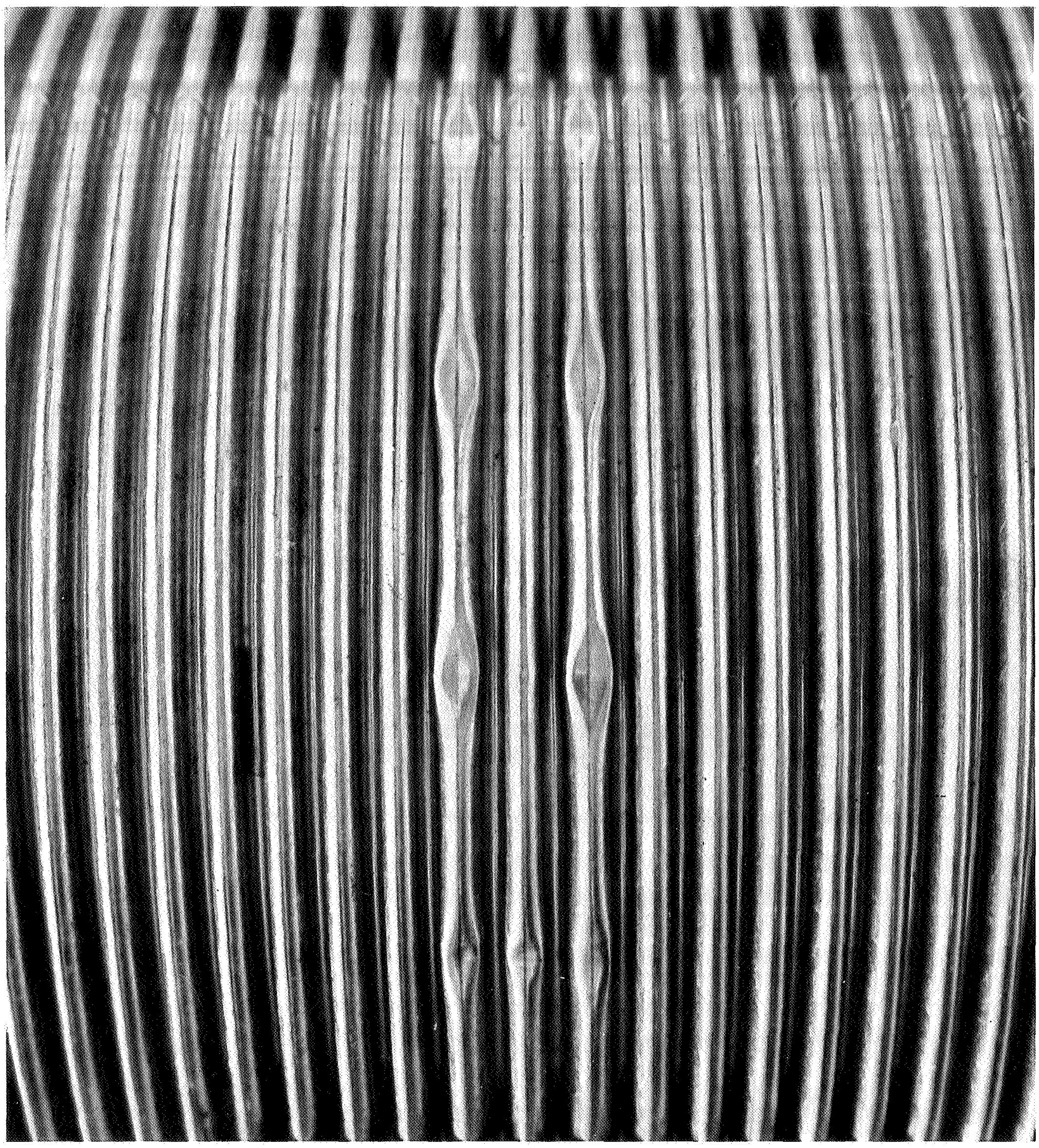
Ruggedness Test Specimens



Ruggedness Test Specimen — Teflon Convolution Protectors
Specimen at 90° — Arm at 80°



Ruggedness Test Specimen — Molded Silicon Rubber
Convolution Protectors
Specimen at 60° — Arm at 70°



Ruggedness Test Specimen — Nylon Convolution Protectors
Specimen at 90° — Arm at 80°

## 3.2.2.3.5 Salt Fog Test

### Test Requirement

The Salt Fog Test was performed to determine the resistance of each test item to a salt fog atmosphere.

### Test Procedure

The test was conducted in accordance with Section 17 of KSC-STD-164D.

Test items were bellows sections approximately six inches long modified per SK4058-3, -4 and -5. One item of each configuration was tested.

Prior to installation in the test chamber, the test item was visually inspected for corrosion, dirt and oily films. Location and extent of corrosion was recorded. Dirt and oily films were removed. The test item was installed in the test chamber as shown on Page 126 and in accordance with Paragraph 4.4.1 of KSC-STD-164D.

After 240 ±2 hours of exposure in a salt fog of 5% salt and 95% water at $95^{+2}_{-4}$ °F the test item was allowed to stand until thoroughly dry.

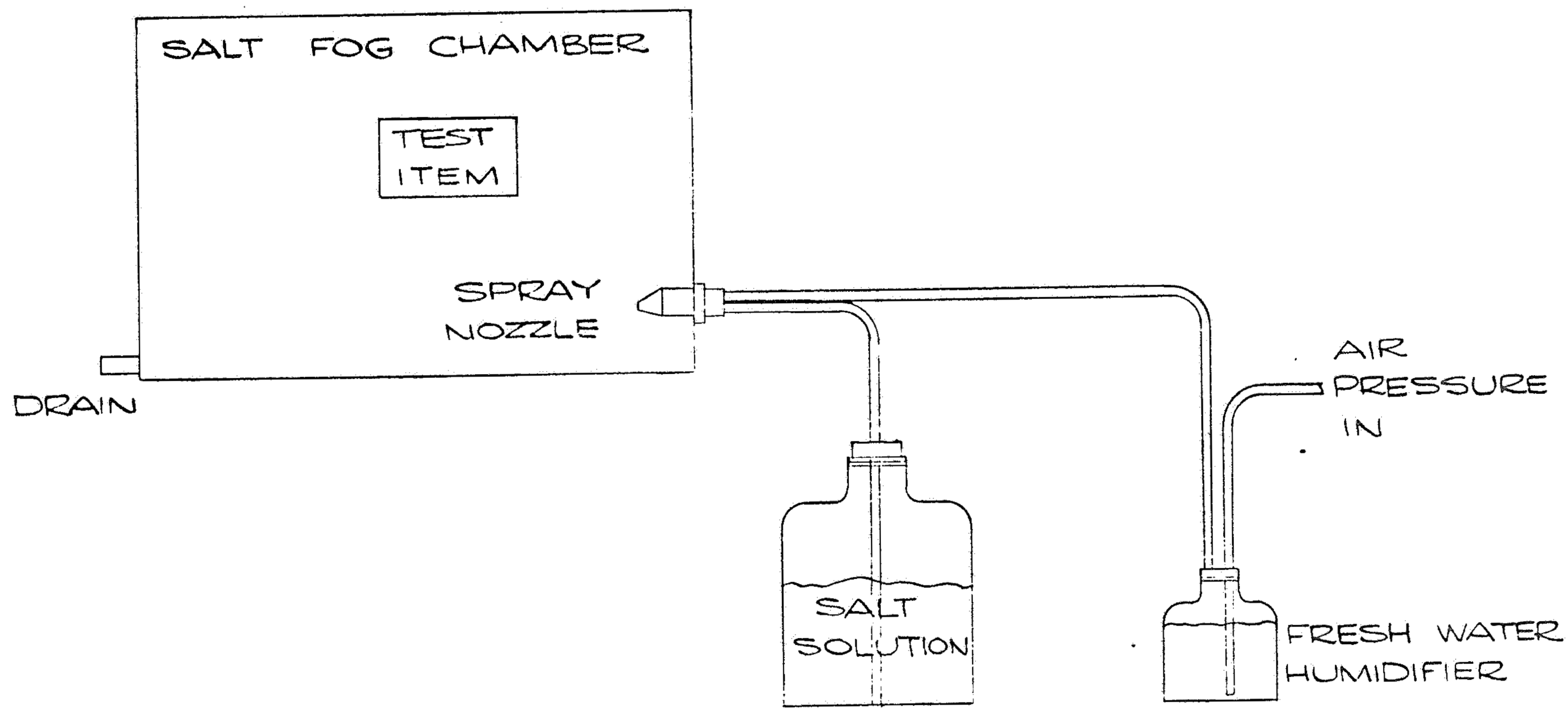
The test item was photographed at the conclusion of the Salt Fog Test while still in the test position. The test item was visually inspected for corrosion. Location and extent of corrosion was recorded.

### Test Results

The results of the Salt Fog Testing conclusively demonstrated that none of the materials used as protective devices are affected by this simulated atmospheric condition. No effects of the test were visible and no material deterioration was observed even when closely inspected.

### Test Data

The data sheets and photographs which begin on Page 127 document the results of the Salt Fog Testing. In the photograph of the test specimen shown after test, the protective devices were peeled back to reveal the bellows convolutions.




Test Set-up, Salt Fog Test

DESIGN VERIFICATION TEST

TEST DATA SHEET

| | | | |
|---|---|---|---|
| Type of Test | Salt Spray | Date of Test | 24 July 1969 |
| Part Name | Bellows Section | Part Number | SK4058-4 |
| Test Procedure | 8-480088 | Part Serial Number | |

| | | | Remarks |
|---|---|---|---|
| Salt Solution | 5 | % | Protective Material - Silicone Rubber |
| Temperature | 95.5 | $^{o}F$ | No evidence of corrosion. |
| Humidity | 98 | % | |
| Air Pressure | 4 | PSIG | |
| Duration of Test | 240 | Hours | |

Test Technician /s/ L. McKnight

Test Engineer /s/ K. Kimble

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Salt Spray Date of Test 24 July 1969

Part Name Bellows Section Part Number SK4058-3

Test Procedure 8-480088 Part Serial Number

| | | Remarks |
|---|---|---|
| Salt Solution | 5 % | Protective Material - RTV Silicone |
| Temperature | 95.5 $^{\circ}$F | No evidence of corrosion. |
| Humidity | 98 % | |
| Air Pressure | 4 PSIG | |
| Duration of Test | 240 Hours | |

Test Technician /s/ L. Mc Knight

Test Engineer /s/ K. Kimble

## DESIGN VERIFICATION TEST

## TEST DATA SHEET

Type of Test: Salt Spray    Date of Test: 24 July 1969

Part Name: Bellows Section    Part Number: SK4058-5

Test Procedure: 8-480088    Part Serial Number: ______

| | | Remarks |
|---|---|---|
| Salt Solution | 5 % | Protective Material - Nylon |
| Temperature | 95.5 °F | No evidence of corrosion. |
| Humidity | 98 % | |
| Air Pressure | 4 PSIG | |
| Duration of Test | 240 Hours | |

Test Technician /s/ L. Mc Knight

Test Engineer /s/ K. Kimble

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Salt Spray

Date of Test 24 July 1969

Part Name Bellows Section

Part Number SK4058-5

Test Procedure 8-480088

Part Serial Number

| | | |
|---|---|---|
| Salt Solution | 5 | % |
| Temperature | 95.5 | °F |
| Humidity | 98 | % |
| Air Pressure | 4 | PSIG |
| Duration of Test | 240 | Hours |

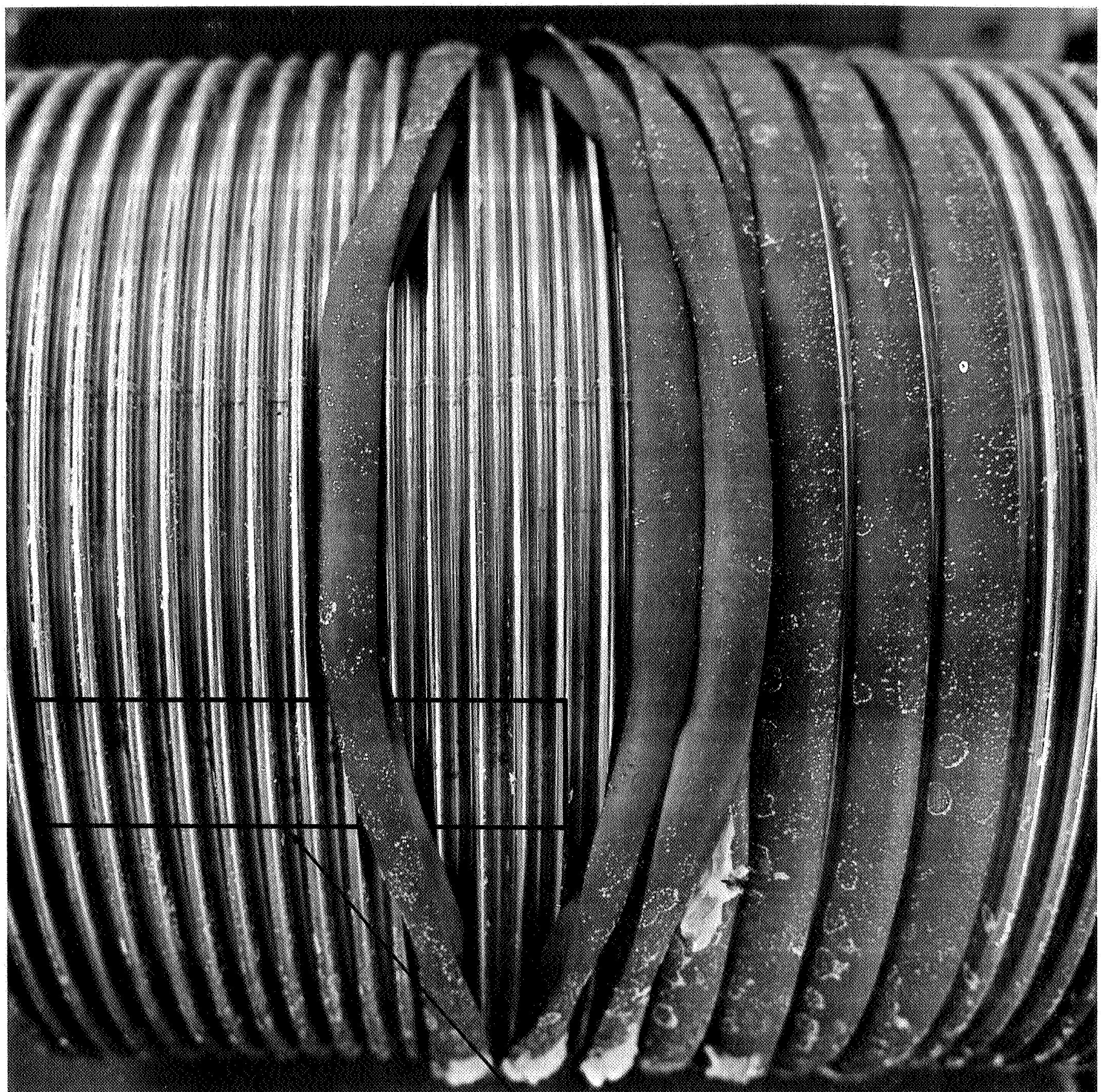
Remarks

Protective Material - Teflon

No evidence of corrosion

Test Technician /s/ L. Mc Knight

Test Engineer /s/ K. Kimble



Unknown Discoloration Which
Existed Prior to Salt Spray Test

Salt Spray Test Specimen (After Test)
Molded Silicon Rubber Convolution Protectors

### 3.2.2.3.6 Low Temperature Test

Test Requirement

The Low Temperature Test was conducted to determine the ability of coating material (Nylon, Teflon and Silicone Rubber) to withstand low temperature thermal shock.

Test Procedure

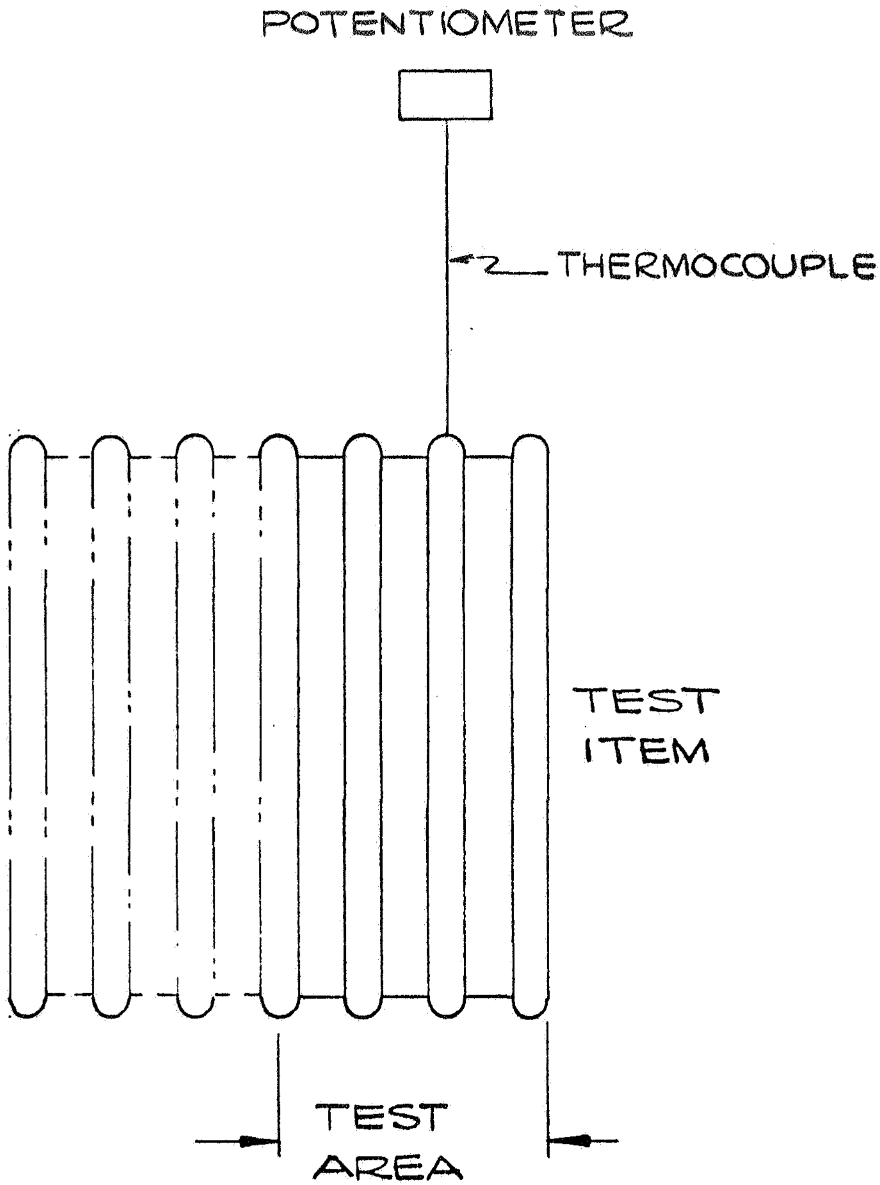
The test items for this test were three (3) bellows sections approximately six inches long, one coated with Nylon, one coated with Teflon, and one coated with Silicone Rubber as shown per SK4058-3,-4 and -5. Each test item was subjected to the following test as shown on Page 133.

A thermocouple was attached and liquid nitrogen was poured over one-half of the outside of the test item until the temperature of the part reached $-100^{\circ}F$. The test item was then allowed to return to room temperature and inspected for defects as a result of this test. This test was performed three (3) times on each test item.

Each test item was inspected after each application of liquid nitrogen for defects, such as cracks, peeling or chipping. The extent and location of any defects was recorded and photographed.

Test Results

None of the specimens were affected in any way detectable by the short time exposure to $-100^{\circ}F$. However, since the test set-up was a simple one and no real information had been generated by the tests to that point, an experimental procedure was undertaken. The specimens were chilled to $-200^{\circ}F$, flexed and also ruggedness tested to a limited degree. Detailed descriptions of the results of this experimental testing is given in the "Remarks" column of each data sheet which follow.




VACUUM JACKETED FLEX HOSE
LOW TEMPERATURE TEST SET-UP

Test Set-Up, Low Temperature

## DESIGN VERIFICATION TEST

## TEST DATA SHEET

**Type of Test** Low Temperature **Date of Test** 15 July 1969

**Part Name** Bellows Section **Part Number** SK4058-5

**Test Procedure** 8-480088 **Part Serial Number** ______

**Test Item Temperature**

-100°F & -200°F

**Remarks**

Protective Material - Teflon.

The specimen was chilled to -100°F and returned to ambient twice with no visible deformation of the Teflon. The specimen was chilled to -200°F and flexed approximately 20° with no visible defects. The specimen was subjected to impact as follows: The impact area was the width of two protective material bands. With the specimen at -200°F, a blow of 65 force pounds was struck with no visible damage. With the specimen at -200°F a blow of 180 force pounds was struck resulting in the following damage: One of the bands cracked approximately one half of its width and the convolution under it dented to approximately .050 inch deep. The second band was not damaged but the convolution under it was dented approximately .040 inch.

**Test Technician** /s/ L. Mc Knight

**Test Engineer** /s/ K. Kimble

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Low Temperature Date of Test 15 July 1969

Part Name Bellows Section Part Number SK4058-4

Test Procedure 8-480088 Part Serial Number

Test Item Temperature

$-100^{O}F$ & $-200^{O}F$

Remarks

Protective Material - Silicone Rubber

The specimen was chilled to $-100^{O}F$ and returned to ambient twice with no visible deformation of the rubber. The specimen was chilled to $-200^{O}F$ and flexed approximately $10^{O}$ with no visible defect.

The specimen was subjected to impact as follows: With the specimen at $-200^{O}F$, a blow of 65 force pounds was struck with no visible damage. With the specimen at $-200^{O}F$, a blow of 180 force pounds was struck with the following results: A very slight indentation was made in the rubber. The impact area was two protective bands each covering two convolutions. Of the four convolutions struck only one showed damage, a dent, of approximately .015 inch in depth.

Test Technician /s/ L. Mc.Knight

Test Engineer /s/ K. Kimble

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test: Low Temperature  Date of Test: 15 July 1969

Part Name: Bellows Section  Part Number: SK 4058-3

Test Procedure: 8-480088  Part Serial Number: 

**Test Item Temperature**

$-100^{\circ}$ and $-200^{\circ}F$

**Remarks**

Protective Material - RTV Silicone.

Specimen was chilled to $-100^{\circ}F$ and returned to ambient twice with no visible deformation of the protective material. The specimen was chilled to $-200^{\circ}F$ and flexed approximately $30^{\circ}$. There was no visible deformation of the protective material. The specimen was impacted at $-200^{\circ}F$ with 65 pounds of force with no visible damage and at $-200^{\circ}F$ with 180 pounds of force with no visible damage.

Test Technician: /s/ L. Mc Knight

Test Engineer: /s/ K. Kimble

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Low Temperature Date of Test 15 July 1969

Part Name Bellows Section Part Number SK 4058-5

Test Procedure 8-480088 Part Serial Number

Test Item Temperature

$-100^{\circ}F$ & $-200^{\circ}F$

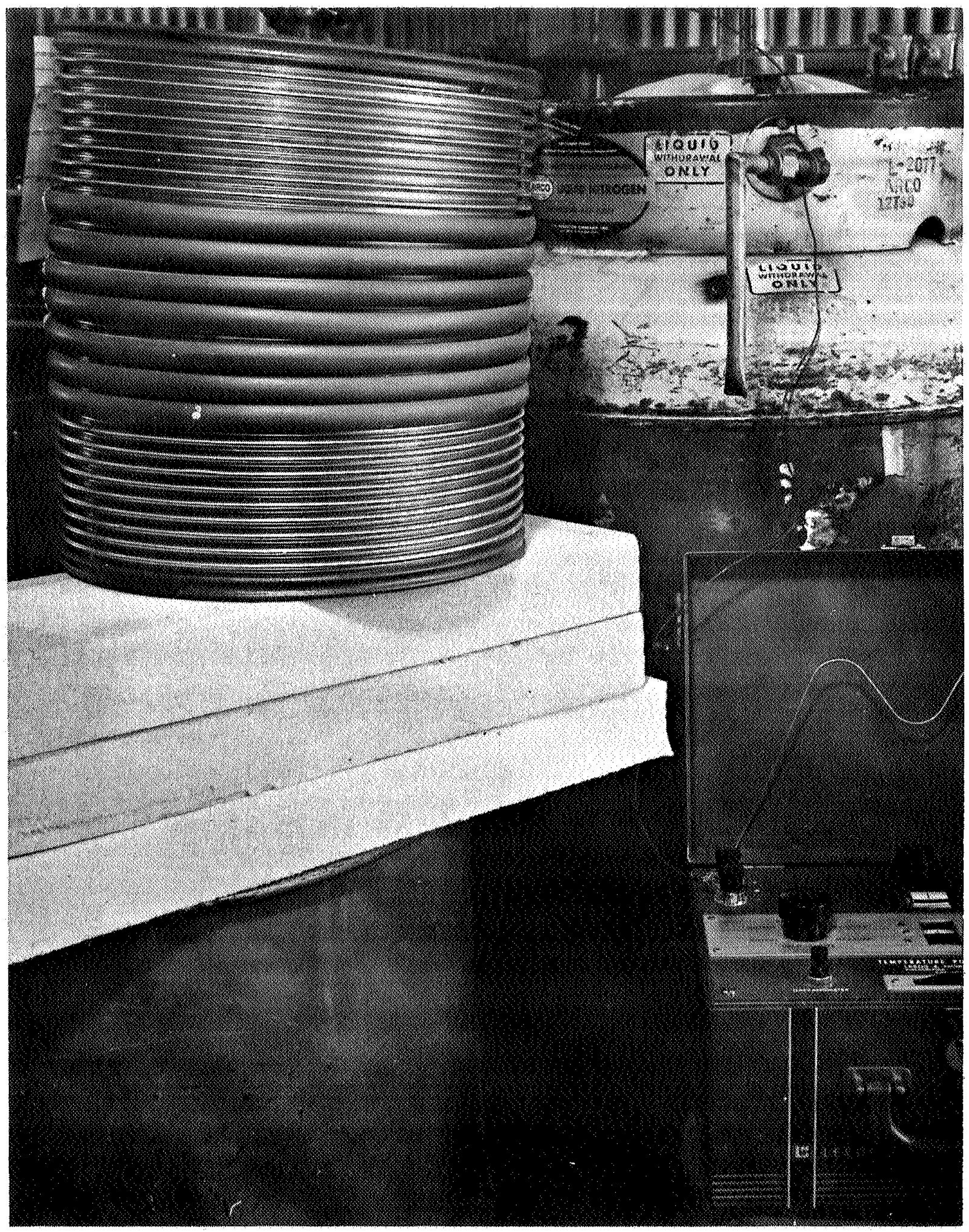
Remarks

Protective Material - Nylon.

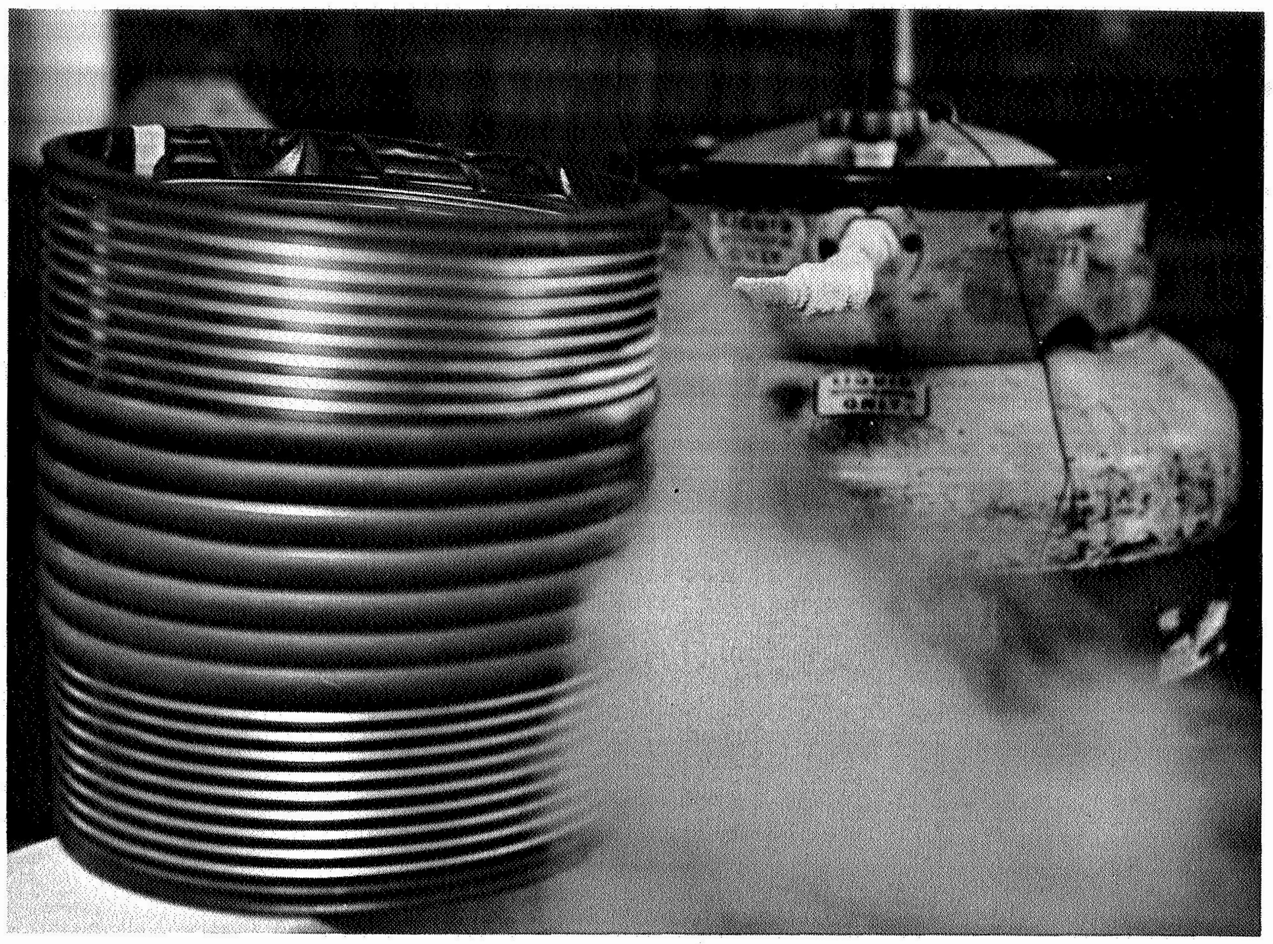
The specimen was chilled to $-100^{\circ}F$ and returned to ambient twice with no visible deformation of the Nylon. The specimen was chilled to $-200^{\circ}F$ and flexed approximately $20^{\circ}$ with no visible defects. Impact area was the width of two protective material bands. With the specimen at $-200^{\circ}F$, a blow of 65 pounds force was struck with no visible damage. With the specimen at $-200^{\circ}F$, a blow of 180 pounds force was struck resulting in the following damage. One of the two bands was cracked the full width of the band and approximately half its depth. The convolution under this band was dented to approximately .050 inch in depth. The convolution below was dented to approximately .015 inch and the one above approximately .010 inch. The second band was not damaged nor the convolution under it.

Test Technician /s/ L. Mc Knight

Test Engineer /s/ K. Kimble




Low Temperature Test Setup



Chilldown of Bellows Test Specimen

3.2.2.3.7 High Temperature Test

Test Requirement

The High Temperature test was conducted to evaluate the test item under the most severe simulated high temperature conditions, that of its expected proximity to the blast of a launch vehicle during lift-off.

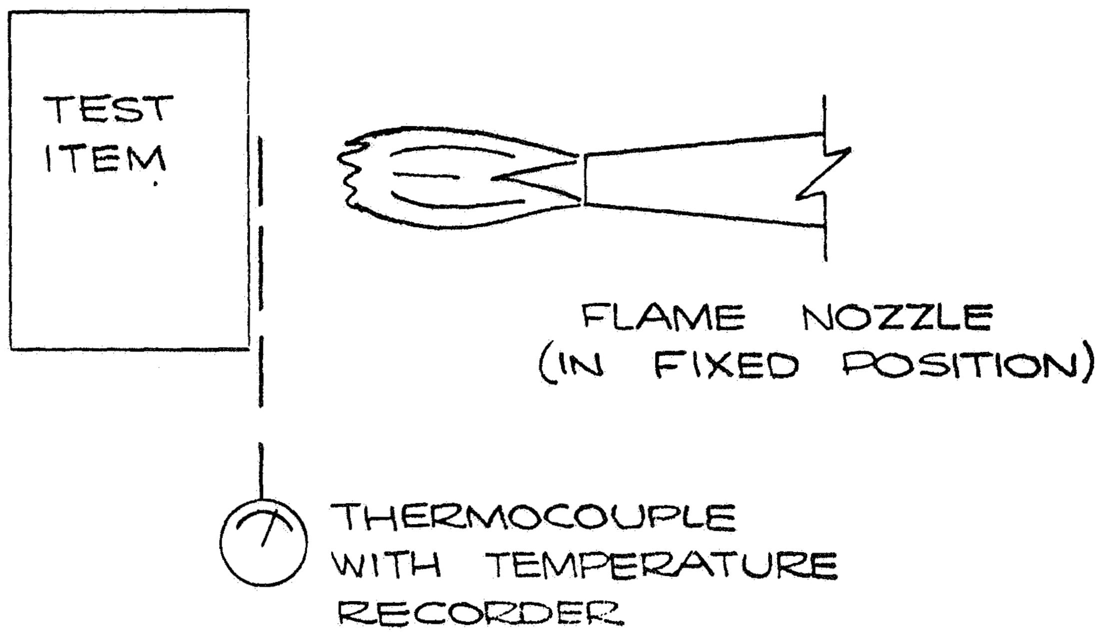
Test Procedure

The test items for this test were short bellows per SK4058-3, -4 and -5. A flame source having the minimum capacity of 1400 ±100°F. was mounted in a fixed position. (See test set-up on Page 141.) The distance from the flame at which the temperature of 1400 ±100°F was attained was determined and marked. The test item was then exposed to the flame at this point for a period of ten (10) seconds.

When the test item was returned to room ambient conditions, it was photographed in the test position and visually inspected. Visible defects as the result of the test were recorded.

Test Results

As depicted on the data sheets and photographs which follow, the Teflon Bumper Strips were apparently unaffected by 10 second exposure to 1400°F. The other protective device materials were damaged as follows: (a) RTV Silicone (cured in place) - slight discoloration, no apparent damage; (b) Silicone Rubber Strips - ignited and tended to sustain combustion after five seconds of exposure; (c) Nylon - distortion and charring immediately; severe damage. Based on this testing, Teflon is obviously superior in this type of environment, however, it should be pointed out that AMS 3004 extrusion grade silicone material was used for the silicone rubber strips which ignited. This is a grade which can, and often does, contain some foreign matter since the specification is somewhat loose in this respect. A more pure composition of silicone and possibly a molded rather than extruded fabrication technique could result in a much better high temperature resistant product.




Test Set-Up, High Temperature

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test: High Temperature — Date of Test: 21 July 1969

Part Name: Bellows Section — Part Number: SK 4058-3

Test Procedure: 8-480088 — Part Serial Number: ________

**Test Item Temperature**

$1400^{\circ}F$

**Duration of Test**

10 seconds

**Remarks**

Protective Material - RTV Silicone

After 10 seconds of exposure to $1400^{\circ}F$, the RTV showed a very slight dark discoloration over about 1/4 of the heat effected area. There was no visible damage to the material.

Test Technician: /s/ L. Mc Knight

Test Engineer: /s/ K. Kimble

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test: High Temperature

Date of Test: 7/21/69

Part Name: Bellows Section

Part Number: SK 4058-5

Test Procedure: 8-480088

Part Serial Number:

| Test Item Temperature | Remarks |
|---|---|
| $1400^{\circ}F$ | Protective Material - Teflon. |
| Duration of Test | After 10 seconds of exposure to $1400^{\circ}F$ |
| 10 seconds | the Teflon showed no visible damage. |

Test Technician: /s/ L. Mc Knight

Test Engineer: /s/ K. Kimble

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test: High Temperature

Date of Test: 21 July 1969

Part Name: Bellows Section

Part Number: SK 4058-4

Test Procedure: 8-480088

Part Serial Number:

Test Item Temperature

$1400^{\circ}F$

Duration of Test

10 seconds

Remarks

Protective Material - Silicone Rubber

After 10 seconds of exposure to $1400^{\circ}F$ the rubber was aflame. Ignition occurred after about 5 seconds after exposure.

Test Technician: /s/ L. Mc Knight

Test Engineer: /s/ K. Kimble

## DESIGN VERIFICATION TEST

## TEST DATA SHEET

Type of Test: High Temperature    Date of Test: 21 July 1969

Part Name: Bellows Section    Part Number: SK 4058-5

Test Procedure: 8-480088    Part Serial Number: 

**Test Item Temperature**

$1400^{\circ}F$

**Duration of Test**

10 Seconds

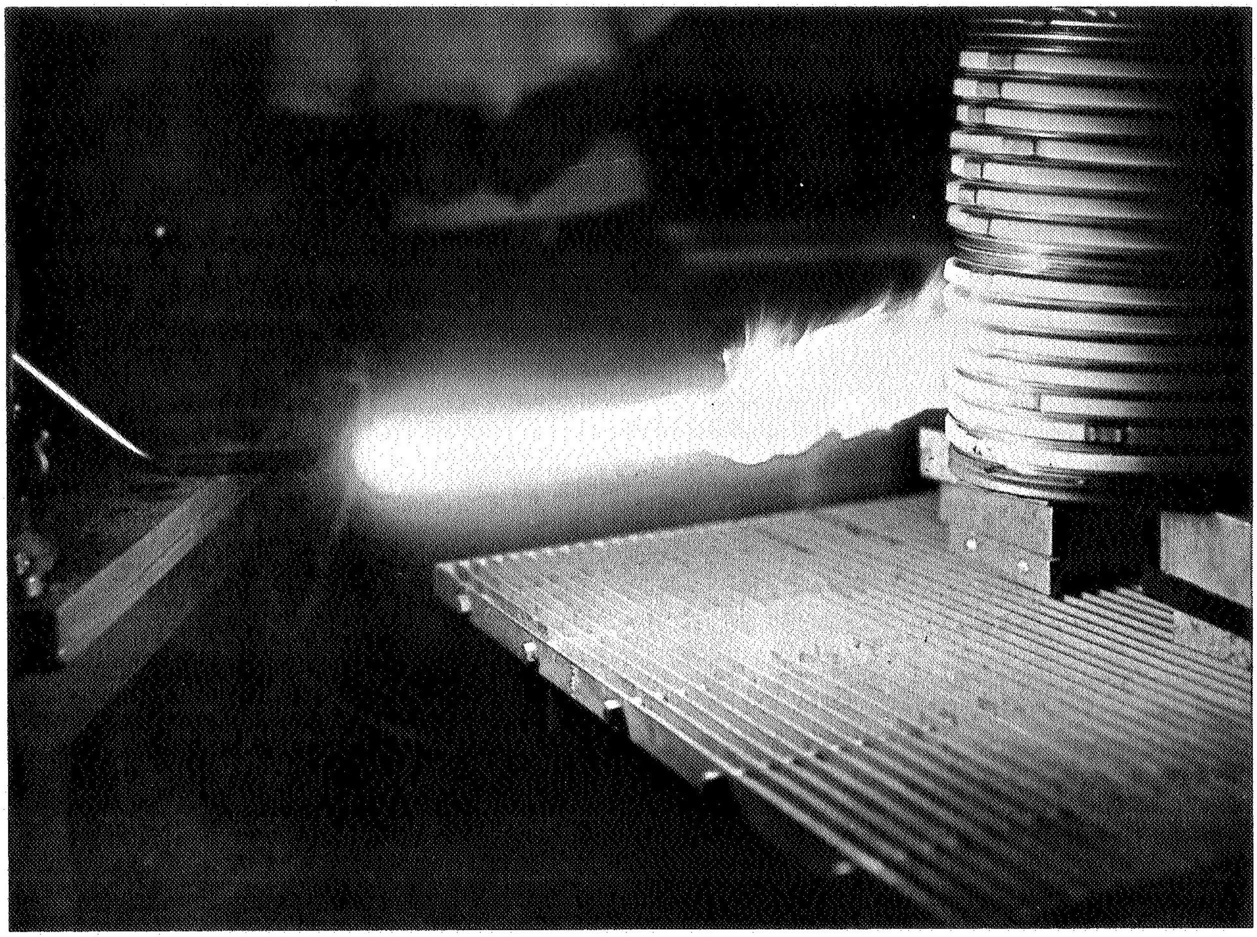
**Remarks**

Protective Material - Nylon.

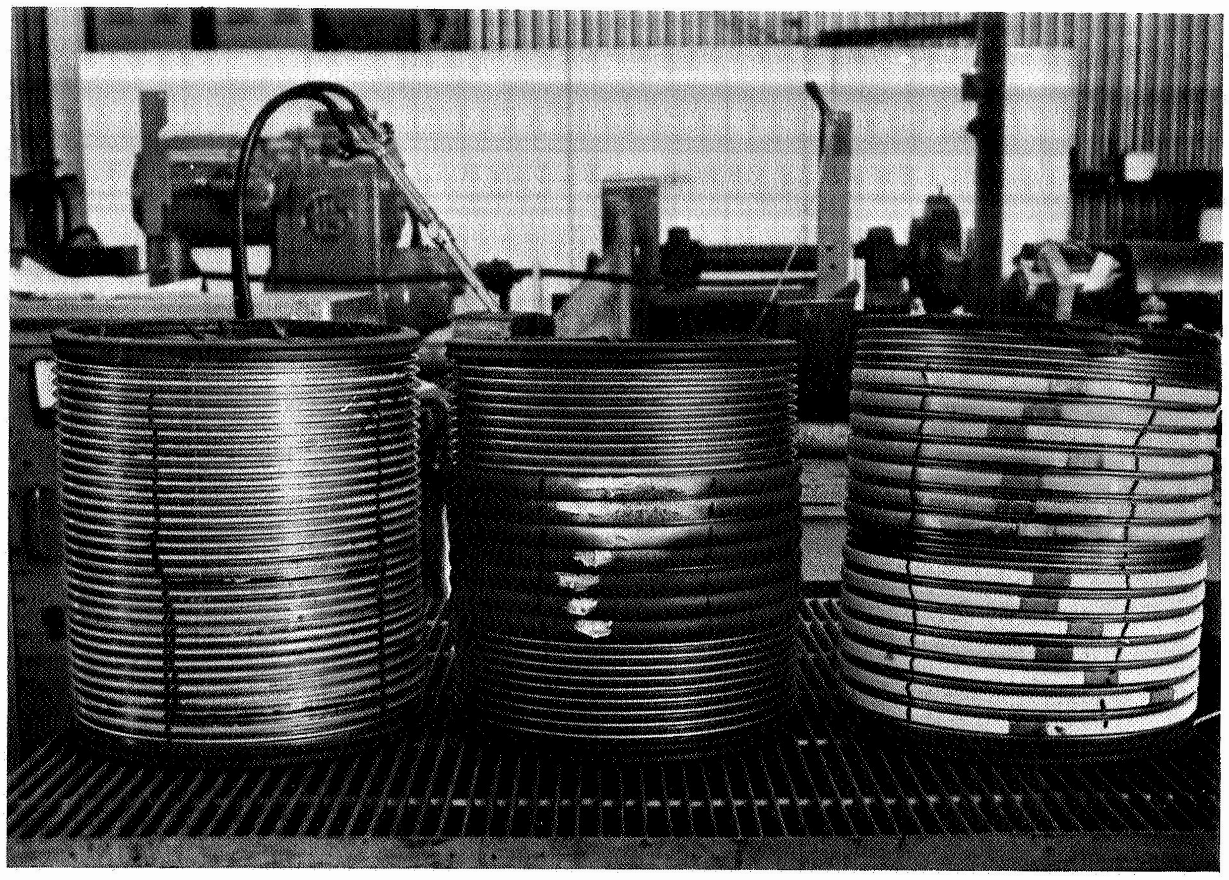
After 10 seconds of exposure to $1400^{\circ}F$, the nylon in the heat effected area was distorted and charred.

Test Technician: /s/ L. Mc Knight

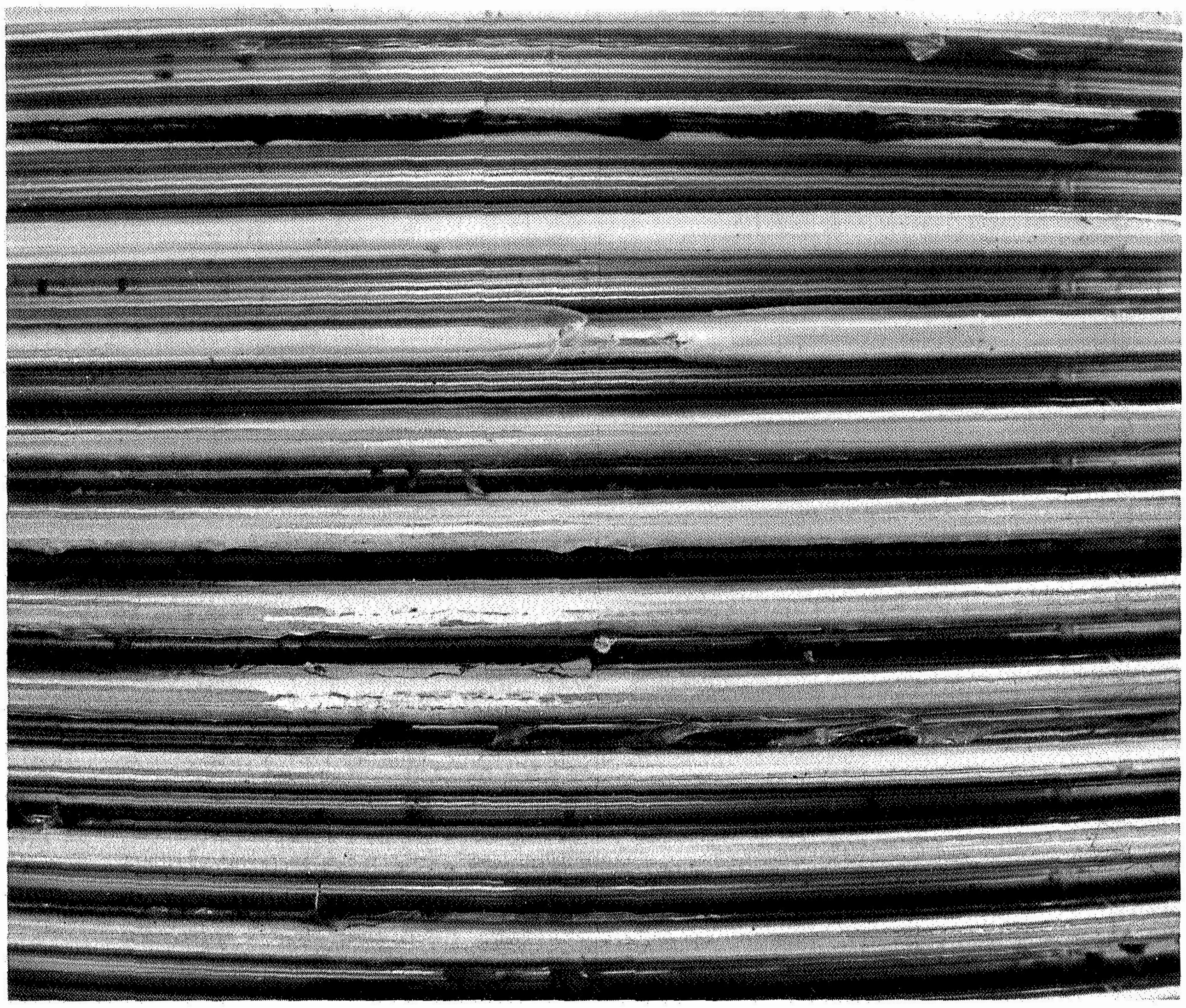
Test Engineer: /s/ K. Kimble



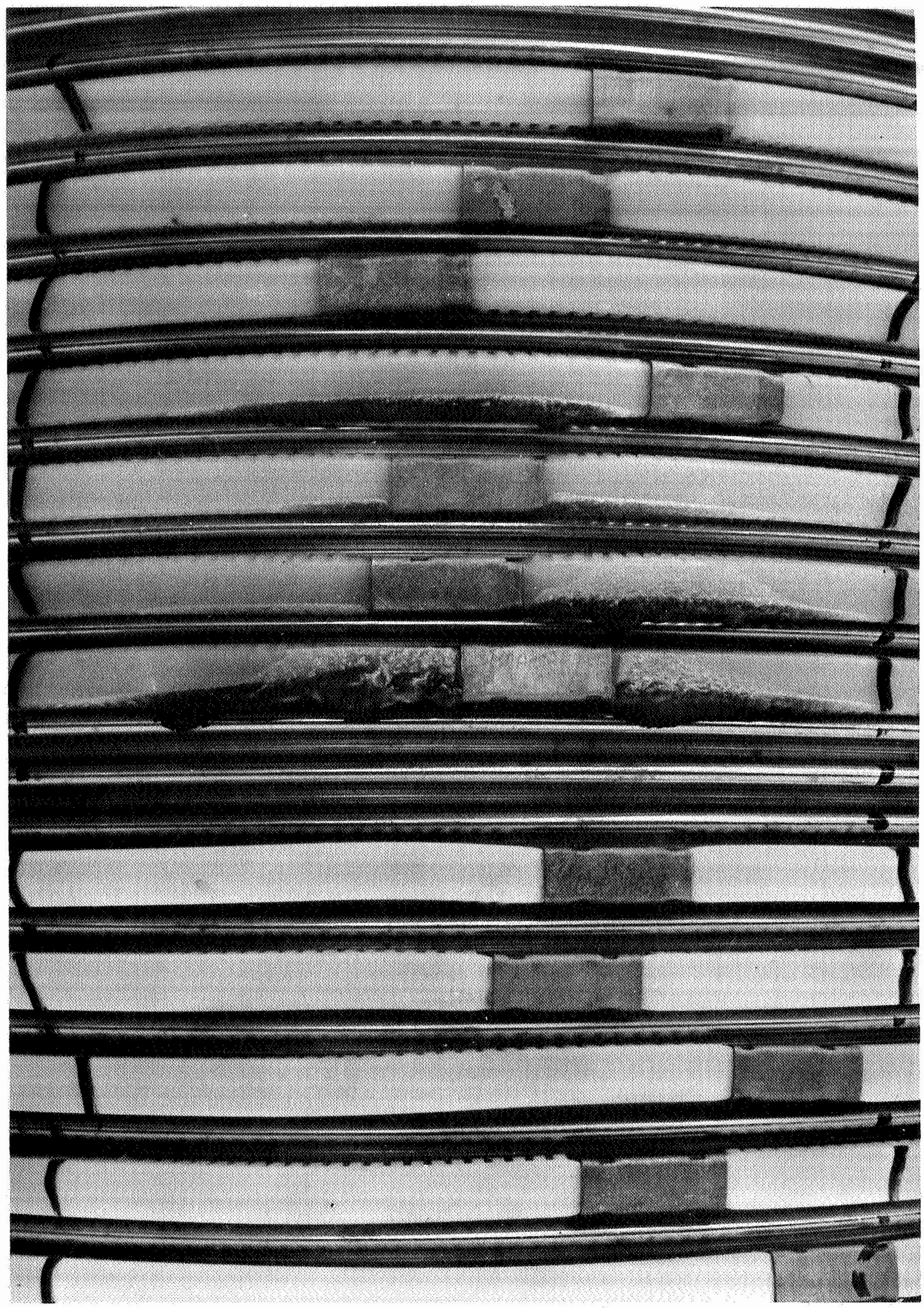
Ruggedness Protection for Bellows Assembly Being Evaluated for Resistance to 1400°F for 10 Seconds



Environmental Test Specimens After Exposure
to 1400°F for 10 Seconds



High Temperature Test Specimen
RTV Silicone Coating After High Temperature Test



Teflon and Nylon Convolution Protectors
After Exposure to 1400°F for 10 Seconds

Silicon Rubber Convolution Protectors After
Thermal Exposure — 1400°F for 10 Seconds

## 3.3.0 CONCLUSIONS

### Bellows Design

Bellows designs for vacuum jacketed flex hoses of the general size, functions and environmental conditions as this study has investigated (service arm cryogenic transfer hoses on Launch Complex 39) are primarily aimed at achieving the greatest flexibility consistent with pressure, ruggedness and fatigue life requirements. The results of this study indicate that .010 inch wall thickness in use for outer jacket bellows is too thin for the ruggedness required to withstand impact and abrasion loads associated with handling, installation and operating conditions. A minimum wall thickness of .016 should be used on any future flex hose designs of comparable size.

### Protective Devices

The concept of using an energy absorbent material between the braid and outer jacket bellows for the purpose of improved ruggedness is feasible and constitutes state-of-art advancement. Although more development is required to optimize the shape of the material, enough testing (see Test Report, Page 60 ) was accomplished to verify that the design is basically sound and practical to use. Material selection as well as configuration must depend on environmental conditions and economic considerations. However, RTV (room temperature vulcanizing ) silicone rubber molded directly onto the circumferential tips of the bellows convolutions is one very promising combination. Whether or not the outer jacket braid could be entirely dispensed with depends on flex hose applications. If one of the protective device materials did replace braid on an outer jacket flex hose, the resistance to bending would not be appreciably altered.

### Flexibility

The resistance to bending of an un-pressurized vacuum jacketed flex hose is reduced by approximately 50% when the braid is removed. Tests also showed that as little as $15^{o}$ of bend will cause braid to take a permanent "set" and not return to normal position when released, even if the line is pressurized. The load to deflect a flex hose is highly sensitive to line length, pressure and bending mode. Bending a braided, pressurized flex hose about a radial arc requires much less force than moving a similar distance by causing the bellows to be offset in two parallel planes.

Resistance to bending increases in either case in roughly direct proportion to pressure and distance moved. The tendency of the braid to lock the bellows in a deflected position once deflection has occurred can be attributed to the braid weave design and little can be done to affect this tendency except possible braid re-design.

Low spring rate bellows should be used on both inner and outer bellows of a V. J. flex line to minimize bending loads, but the most critical factor in flexibility is line routing geometry. It is concluded that parallel offset bending should be avoided wherever possible and when unavoidable such lines should be as long as feasible and should be supported by flexible slings.

## 3.4.0 RECOMMENDATIONS

### Flex Line Design

It is recommended that a minimum of .016 inch wall thickness replace all .010 inch thick outer jacket bellows material for all line sizes and configurations in present use and for future designs. This study has shown that an increase in convolution height can compensate for added wall thickness and further that braid and bending mode are more critical to overall line flexibility than a small increase in bellows wall thickness.

Single ply bellows are recommended rather than multiple-ply construction based on greater ruggedness and reliability.

This study does not obviate the need for the wire braid on the outer jacket, however future study might indicate that energy absorbent material could entirely replace the braid. The need for energy absorbent material to protect the outer jacket of a vacuum jacketed flex line is shown in the Phase I Technical Report and it is recommended that a material equivalent to transparent RTV (room temperature vulcanizing) silicone rubber be molded to the outer bellows convolutions. The thickness of the rubber should be determined by the magnitude of force expected to be encountered in service. For flex lines used in an application such as those at Launch Complex 39 on the LUT, a thickness of .094 to .125 inch is indicated by tests to be very effective.

### Additional Study

A. Wire Braid

The research efforts and testing program results indicate that a considerable information gap exists in the area of tubular wire braid design, application and affect on flex hoses. The efforts of this study were unique in exploration of braid design and indicate the need for further study. It is recommended that a study of braid angle, weave design, wire materials, coatings and wire sizes be given consideration. The results of such a study will lead to a more detailed knowledge of the mechanical relationships of braid as related to total flex hose design.

B. Cycle Life

Although this study program did establish new data on bending loads of flex hoses, both jacketed and non-jacketed, it was not within the scope of the test plan to evaluate cycle life and failure modes due to flex cycling of jacketed lines. The exact nature of flexural fatigue failure with varying degrees of damage would be valuable information and a program of study is therefore recommended.

C. Bending Loads

Ability to calculate bending loads of braided flex lines is lacking in current technology. A study of means to accomplish this type of calculation should be undertaken. Such a study should be aimed at development of enough test data of various line configurations to insure a reliable analytical approach.

## 3.5.0 DESIGN SPECIFICATIONS

Due to the wide variations in applications of flex hoses requiring specific designs for each individual case it would be impossible to generate one or even a family of procurement specifications to serve all cases. Therefore the following Design Guide is given to serve as a source of state-of-art flex hose design criteria as updated by this study program.

### Bellows

Bellows should be single ply of sufficient thickness to withstand normal handling. Multiple ply bellows should be avoided on flex hoses due to high cost and non-repairable nature of the assembly. Where extreme flexibility and long cycle life are required of a short flex hose, multiple ply bellows design may be the only answer. However, a close-pitch, high convolution bellows is usually the best design for a combination of long flex life and reliability.

## Braid

One aspect of bellows design not widely understood is pressure instability or "squirm". This happens when a bellows is pressurized beyond its capacity to maintain its shape and tends to curl or twist over its length. Normally this is not a problem with flex hose since tubular wire braid is used to contain the bellows and the stability is maintained throughout the design pressure range since the higher the pressure the greater the end load on the braid and the tighter it encloses the bellows. However, the effectiveness of the braid enclosure is dependent on the angle of the braid weave. Thus it must be specified that the braid angle (normally $45^{o}$ to $55^{o}$) be such that squirm is not possible.

The end attachment of braid on a flex hose is the weakest point in the braid if it is welded since the heat affected zone of the weld area is annealed and the rest of the braid wire is somewhat strain hardened. Stress analysis should always take this into consideration and braid should be selected and specified accordingly. In the case of vacuum jacketed flex hose the inner line braid should be sized to carry the entire end load due to pressure. Outer jacket braid should be optional depending on method and extent of outer jacket protection.

## Protective Devices

Whether outer jacket braid is used or not, protective covering of the bellows is needed. The degree of flexibility of the line will be similar in either case. A material equivalent to 1/8 inch of RTV silicone rubber is suggested as a molded bellows convolution protective bumper. The degree of protection should be specified by maximum damage which can be allowed while still maintaining reliable function of the flex hose. This should be determined by qualification testing with an impact tester and flexural fatigue testing.

## General Design

Where it is desirable that a vacuum jacketed flex hose be repairable in the field then the outer jacket braid should have mechanical end attachments rather than welded or brazed. If the hose is complex enough that repairs of many types of damage can be economically considered then the welding of end flanges or connections should be designed such that removal and replacement is possible.

CRES Type 316L is currently the best available material for flex hose assemblies exposed to salt spray environment. However, corrosion will still be a problem if welds are wire brushed with contaminated brushes or if welds are not passivated thoroughly. As a general rule of thumb, centerline bend radii for hoses in the diameter range of six to twelve inches should be about ten times the hose diameter as a minimum. This ratio will go up for larger sizes and decrease somewhat for smaller sizes. It can be expected that one thousand cycles of bending about such radii can be designed for without special development problems. Standoffs between inner and outer jacket bellows which maintain concentricity should be low heat conduction material which will not damage the bellows. Polytetrafluorethylene has proven satisfactory in the past in both aspects and is recommended.

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